Age, Sex, and Racial/Ethnic Disparities and Temporal-Spatial Variation in Excess All-Cause Mortality During the COVID-19 Pandemic: Evidence from Linked Administrative and Census Bureau Data

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Abstract

Research on the impact of the COVID-19 pandemic in the United States has highlighted substantial racial/ethnic disparities in excess mortality, but reports often differ in the details with respect to the size of these disparities. We suggest that these inconsistencies stem from differences in the temporal scope and measurement of race/ethnicity in existing data. We address these issues using death records for 2010 through 2021 from the Social Security Administration, covering the universe of individuals ever issued a Social Security Number, linked to race/ethnicity responses from the decennial census and American Community Survey. We use these data to (1) estimate excess all-cause mortality at the national level and for age-, sex-, and race/ethnicity-specific subgroups, (2) examine racial/ethnic variation in excess mortality over the course of the pandemic, and (3) explore whether and how racial/ethnic mortality disparities vary across states.

Keyword*:* COVID-19; Excess Mortality; Mortality Disparities; Race/Ethnicity

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I. Introduction

According to National Center for Health Statistics (NCHS) estimates, in February 2022 the United States surpassed 1 million excess deaths (that is, observed deaths exceeding the expected number of deaths given mortality trends in the recent past) since the start of the COVID-19 pandemic in early 2020.[1] Conservative estimates of the impact of these excess deaths, based on data prior to the Delta wave in late 2020 and early 2021, suggest a decline in life expectancy at birth greater than one year (Andrasfay and Goldman 2021; Woolf, Masters, and Aron 2021). But excess deaths and declines in life expectancy have been spread unevenly across the United States and its population. Particularly striking is research highlighting substantial racial/ethnic disparities in excess mortality, finding higher rates of excess mortality for some minority groups, such as Hispanics and non-Hispanic Blacks, and lower excess mortality among non-Hispanic Asians and non-Hispanic Whites (Arias, Tejada-Vera, and Ahmad 2021; Bassett, Chen, and Krieger 2020; Goldstein and Atherwood 2020; Luck et al. 2021; Polyakova et al. 2021; Rossen et al. 2021; Solis et al. 2020).

Though studies consistently support the general finding that the impacts of the pandemic are disparate, they vary with respect to the size of disparities by age, sex, race/ethnicity, and geography and, therefore, offer differing assessments of which groups and places are most heavily impacted by the pandemic. For example, Polyakova et al. (2021) find that age-adjusted excess all-cause mortality was 4.17 times greater for non-Hispanic Blacks and 2.29 times greater for Hispanics than for non-Hispanic Whites, while Luck et al. (2021) estimate that non-Hispanic Blacks and Hispanics have, respectively, 2.45 and 2.17 times the excess mortality of non-Hispanic Whites. Examining racial/ethnic gaps in deaths directly attributable to COVID-19, Goldstein and Atherwood (2020) estimate that age-adjusted death rates are 2.7 times greater for Blacks and 1.9 times greater Hispanics than for Whites at the national level. Similarly, while some studies of the early pandemic period find the largest racial/ethnic mortality gaps in New York and New Jersey (Polyakova et al. 2021), others locate the largest gaps in states like Wisconsin and Illinois (Goldstein and Atherwood 2020).

While some of the variation in estimates of the pandemic's impacts is attributable to different approaches to estimating and quantifying mortality (i.e., estimating excess all-cause mortality versus COVID-19 mortality, or quantifying effects in terms of excess deaths versus changes in life expectancy), variation also stems from differences in the coverage and granularity of mortality data used. Perhaps the largest source of variation in estimates, however, is differences in the temporal scope of the data used. To provide timely estimates of excess mortality, early research relied on data covering only a few months of pandemic mortality. As more recent studies incorporated a longer range of pandemic data, estimates of mortality gaps changed, potentially reflecting a host of factors including (but not limited to): regional shifts in COVID-19 prevalence (Gold et al. 2020; Kumar et al. 2021); vaccine availability and uptake (Nguyen et al. 2021); and social distancing behaviors (VoPham et al. 2020). In addition to temporal scope, data also tend to differ with respect to how racial/ethnic identity is reported. While some research utilizes next-of-kin and coroner assessments on death certificates, which can be inaccurate and biased for some groups (Arias et al. 2008; Arias, Heron, and Hakes 2016) other research relies on aggregate death counts reported at the state level for racial/ethnic groupings that vary from one state to the next.

[1] See https://www.cdc.gov/nchs/nvss/vsrr/covid19/excess_deaths.htm.

The primary goal of this paper is to address some of the variation in prior research discussed above – particularly variation rooted in various aspects of data quality – by taking both a broad view of the first full year of the pandemic and, at the same time, examining granular variation in excess mortality by age, sex, race/ethnicity, month, and state. Specifically, we (1) estimate excess all-cause mortality at the national level and for age-, sex-, and race/ethnicity-specific subgroups, (2) examine racial/ethnic variation in adjusted excess mortality over the first full year of the pandemic, and (3) explore whether and how temporal trends in racial/ethnic mortality disparities reflect changing geographic patterns in COVID-19 cases. We use restricted-access administrative records from the Social Security Administration (SSA), covering the universe of individuals ever issued a Social Security Number (SSN), linked to a variety of decennial census, administrative record, and Census Bureau survey data at the individual level. In so doing, we take a broader perspective on the impact of the pandemic in its first full year, while also producing granular estimates of variation in mortality by month, state of residence, and self-and proxy-reported race/ethnicity.

Nationally, we estimate an excess all-cause mortality rate of 1.8 per 10,000 person-months (PM) or 216 per 100,000 person-years for the April 1, 2020 to March 31, 2021 period – the first full year of the COVID-19 pandemic. But this national figure masks substantial variation in excess mortality across demographic subgroups, as well as temporal and geographic variation in the pandemic's first year. Excess mortality is higher among males (2.1 per 10,000 PM) than females (1.6 per 10,000 PM) and, though some racial/ethnic groups experienced relatively high excess mortality among those of working age, excess mortality increases monotonically across the age distribution and is concentrated among those over age 65. Age- and sex-adjusted excess mortality rates were far higher among non-Hispanic (NH) American Indian/Alaskan Native alone (4.7 per 10,000 PM), Hispanic (3.6 per 10,000 PM), and NH Black alone (3.5 per 10,000 PM) individuals relative to their NH White alone counterparts (1.4 per 10,000 PM), with Hispanics seeing the largest proportional increase (49.1 percent) in mortality of any group. Racial/ethnic, temporal, and spatial trends are consistent with the notion that the social and economic determinants known to drive health disparities in the pre-pandemic era also operated during the pandemic to disproportionately increase mortality among disadvantaged racial/ethnic minority groups.

II. Background

Though the COVID-19 pandemic's impact on the U.S. population as a whole has been devastating, research consistently shows that the impacts are spread unevenly across the population. Most COVID-19 deaths occur to individuals aged 75 and older (Rossen et al. 2020), and excess mortality has been shown in many studies to have been disproportionately concentrated among Hispanics, non-Hispanic Blacks, and American Indian/Alaskan Native populations (Arias et al. 2021; Bassett et al. 2020; Goldstein and Atherwood 2020; Luck et al. 2021; Polyakova et al. 2021; Rossen et al. 2021; Solis et al. 2020). Studies examining excess mortality by age and race/ethnicity simultaneously, however, have shown that although older populations are disproportionately impacted by the pandemic, some racial/ethnic groups experienced sizeable increases in mortality even among younger, working age populations (Rossen et al. 2021). These racial/ethnic differences in excess mortality across the age distribution are fully realized when quantified in summary estimates of mortality over the life course, such as life expectancy (Andrasfay and Goldman 2021; Woolf et al. 2021) or years of potential life lost (Bassett et al. 2020).

Research has also shown that racial/ethnic disparities in excess mortality during the pandemic vary significantly both over time and across the United States. Polyakova et al. (2021) show that, though non-Hispanic Blacks and Hispanics had higher excess mortality rates than non-Hispanic Whites in most states at the start of the pandemic, gaps were much larger in some states (like New York and New Jersey) than in others. Examining early deaths from COVID-19, specifically, Goldstein and Atherwood (2020) locate the largest gaps Black-White and Hispanic-White gaps in states like Wisconsin and Illinois, respectively. But data covering an increasing portion of the pandemic shows that racial/ethnic gaps in mortality changed significantly as the pandemic wore on. For example, studies suggests that the Black/White mortality ratio fell from 3.57 in April 2020 (Bassett et al. 2020) to 2.37 in May 2020 (Gross et al. 2020), then subsequently fell to 1.47 by January 2021 (Stokes et al. 2021). Some evidence suggests that these changes in racial/ethnic disparities may be attributable, at least in part, to changes in the regional prevalence of COVID-19 – that is, the dispersion of the virus from a handful of large, diverse population centers to a broader, less diverse, set of states (Gold et al. 2020; Kumar et al. 2020). But Lawton et al. (2021) find the regional dispersion explanation insufficient, arguing instead that policy and behavior changes affecting exposure to COVID-19 within places, not across them, are more important for explaining racial/ethnic disparities over time.

Temporal and geographic variation in excess mortality and racial/ethnic disparities provides strong suggestive evidence that social and economic determinants, which have been shown to drive disparate health outcomes generally, also drive racial/ethnic disparities in pandemic mortality. Recent research from Dalsania et al. (2022), for example, has linked county-level COVID-19 death rates to a host of distal socioeconomic health determinants, finding higher mortality rates in places with larger minority, uninsured, high school dropout, and incarcerated population shares. Aggregate population characteristics like these may serve as proxies for or indicators of "mutually reinforcing, inequitable systems – referred to as structural racism – which could ultimately influence the way in which minorities experience COVID-19 and other illnesses (Dalsani et al. 2022: 289)," by shaping either individual exposure and infection probabilities or the probability of death contingent on infection, or both. It should be noted, however, that the latter of these pathways operates primarily via racial/ethnic differences in access to quality care, not via racial/ethnic differences in the biological impact of COVID-19 (Shortreed et al. 2022). Racial/ethnic gaps in mortality during the pandemic have also been linked to a host of more proximate factors governing both exposure/infection and mortality contingent on infection, including (but not limited to): differences in household size and the ability of household members to work from home (Selden and Berdahl 2020); differences in air quality and access to health care (Magesh et al. 2021; Rozenfeld et al. 2020); the disproportionate representation of racial/ethnic minorities in lower-status essential occupations (Goldman et al. 2021); and racial/ethnic differences in vaccine hesitancy and access (Nguyen et al. 2021). Note, however, that pre-pandemic racial/ethnic health disparities –while sizeable – are not sufficient to explain gaps in excess all-cause or COVID-19-specific mortality during the pandemic. We return to this point later in our analysis.

Properly understanding the origin and persistence of racial/ethnic gaps in mortality requires accurate and detailed estimates of those gaps. Though adjudicating the precise mechanisms underpinning racial/ethnic disparities in excess all-cause mortality is beyond the scope of this paper, we aim to provide detailed and circumspect estimates of excess mortality one year into the pandemic. Our hope is that these estimates inform ongoing research on the causes and consequences of stark racial/ethnic disparities by clarifying temporal-spatial trends in mortality for age-, sex-, and race/ethnicity-specific groups.

III. Data and Methods

III.A Data

Data used in this analysis are comprised of a combination of administrative and third-party records, decennial census records, and Census Bureau survey responses. As discussed below, these records, when linked with one another, facilitate the measurement of monthly excess all-cause mortality for the population ever issued a Social Security Number (SSN) by detailed demographic groups, at both the national and state level.

Measuring Mortality

The Census Numerical Identification database (Numident) serves as the backbone of our analysis, providing date of death information for the U.S. population through March 2021 (Finlay and Genadek 2021).[2] The Numident file is a federal administrative record containing anonymized information on the population ever issued a Social Security Number (SSN) by the Social Security Administration (SSA). SSNs were first created and issued in 1936 and have been tracked electronically in the Numident since 1972. By definition, this file excludes the population never issued an SSN.

The Numident includes date of death information for the universe of individuals issued an SSN from a variety of sources, including "first-party reports of death from family members and representatives and verified third-party reports from friends, state government offices, the Centers for Medicare and Medicaid Services, the Department of Veterans Affairs, and the Internal Revenue Service (Finlay and Genadek 2021:142)." Death reports prior to 1962 are incomplete in early versions of the Numident, particularly for younger SSN holders. Improved methods implemented in 2005 and 2019 correct underreporting at younger ages and fill in missing reports for many deaths back to 1960. As a result, recent vintages of the Numident provide death data for the U.S. population that are more comprehensive than other commonly used sources, such as the publicly available Death Master File, and which yield annual and weekly all-cause death counts that are virtually identical to vital statistics released by the CDC's National Center for Health Statistics (NCHS), even during the pandemic (Finlay and Genadek 2021).

Although counts of deaths in the Numident are quite comparable to those from NCHS, issues arise when death counts are expressed as rates – that is, over the population at risk. Like other mortality studies relying on death records, an important source of potential bias in the Numident is the right-censoring of observations. While the Numident includes anyone ever issued an SSN, it does not successfully capture the date of death for every decedent. Because Numident death reporting prior to 1960 is less comprehensive, we restrict our analysis throughout to the population under 100 years of age. But, even after 1960, death record coverage

[2] Specifically, the 2021 (Q3) version of the Census Numident is used in this analysis. Due to lags in the delivery and incorporation of death records into the Numident, comparisons of aggregate death counts in the Numident with those from the NCHS suggest that the 2021 (Q3) Numident accurately reports deaths through March 2021, but may undercount deaths thereafter. These undercounts will, of course, be addressed as future vintages of the Numident are made available.

is less than complete due to both linkage issues and the difficulties inherent in tracking deaths among emigrants. Though a valid death record for an individual might exist, SSA may not be able to link it to the correct SSN. Similarly, though SSA does collect information on deaths of SSN holders occurring abroad (Finlay and Genadek 2021), geographic and political barriers may decrease date of death coverage among those dying outside the United States. To assess the sensitivity our results to the inclusion of likely right-censored observations, we conducted all analyses presented here with an additional restriction of our analytical universe (see below) to the population that was enumerated in the 2010 decennial census. Restricting our universe in this way does not change any of the substantive results presented but does have the general effect of increasing observed mortality rates, particularly among groups disproportionately likely to emigrate, by removing those whose deaths are least likely to be recorded in the Numident.

Note, however, that the Numident does not record cause of death. For this reason, we measure mortality from all causes throughout this paper. While this all-cause measure limits our ability to delineate the precise mechanisms driving mortality, it nevertheless provides a better indicator of the pandemic's overall impact on mortality in the United States, incorporating both the direct impacts of COVID-19 as well as any indirect effects (whether positive or negative) on mortality via changes in economic well-being, mental health, drug/alcohol abuse, accidental deaths, homicides, and/or health care resources, access, and utilization (e.g., Luck et al. 2021).

Measuring Age, Sex, and Race/Ethnicity

We calculate age-, sex- and race/ethnicity-specific mortality rates by linking the Numident to 2000 and 2010 decennial[3] and 2001-2019 American Community Survey (ACS) responses. Age and sex are obtained from the Numident, which in addition to date of death contains sex and date of birth information. We present age-specific results in 5-year age bins (15-19, 20-24, …, 90-94, 95-99) for those between 15 and 99 years of age at the start of any given month. Though sex is not naturally a binary trait and is subject to change over time (Harris 2015), it is captured as a binary variable on the Numident and is treated, by necessity, as constant and binary in this analysis.

Much of the prior research on racial/ethnic disparities in excess mortality related to COVID-19 relies on death certificate race reports or on aggregated state-level mortality statistics. Evidence suggests that race reporting on death certificates is subject to bias and misreporting from coroners, medical examiners, and next of kin, and is particularly poor for American Indian/Alaskan Natives and somewhat unreliable for Hispanics, Asians, and Pacific Islanders (Arias et al. 2008, 2016). The use of aggregate state-level mortality statistics to evaluate national race/ethnicity-specific trends is complicated by the fact that race/ethnicity categories vary from state to state and follow no central standard (Stokes et al. 2021).

We circumvent these data challenges using self-reported and household proxy race/ethnicity from Census Bureau sources. Because an individual's racial and ethnic identification is fluid and subject to change over time (Liebler et al. 2017), we retain the most recent race/ethnicity report for a given individual from among all available decennial and ACS responses for that individual. Imputed values are included throughout this process. The resulting race/ethnicity categories[4] include Hispanic (any race), Non-Hispanic (NH) White Alone, NH

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[3] Though the 2020 enumeration was complete as of the drafting of this paper, a research file was not available for use.

[4] Race and Hispanic origin data are presented following the guidance of the U.S. Office of Management and Budget's (OMB) 1997 Revisions to the Standards for the Classification of Federal Data on Race and Ethnicity.

Black or African American Alone (Black here), NH American Indian or Alaskan Native Alone (AIAN), NH Asian Alone, NH Native Hawaiian or Other Pacific Islander Alone (NHPI), NH Some Other Race (SOR) Alone, and NH Multiple Race.

Measuring State of Residence

Annual state of residence information for individuals on the Numident file for the 2010 to 2021 period is obtained from a variety of administrative record, third-party, decennial census, and survey data. We use the most recent from among these various sources to assign a state of residence each year and, if an individual's state is missing in that most recent source, we rank remaining sources by recency and quality and assign the first non-missing state location working down that ranking.

For example, the timeliest source of state location data in 2010 is the decennial census, and most individuals' 2010 state locations come from their decennial response. For those missing a decennial state location in 2010, we then attempt to pull state locations from the Census Bureau's Master Address File – Auxiliary Reference File (MAF-ARF) for 2010, a composite administrative record file combining location information from the Internal Revenue Service (IRS), the Department of Housing and Urban Development (HUD), and a variety of other federal agencies. If state location is missing in both decennial and MAF-ARF data, we last check for a 2010 ACS response and, if non-missing, record state of residence as reported there. It is important to note that, though the ranking of our location sources changes between 2010 and 2021, all sources available for a given year are used to assign the last known state of residence; when these year-specific sources lack a state location, we assign the last known state location, looking as far back as 2010 to do so. For the 2011 to 2014 period, we rank sources as follows: MAF-ARF; ACS; 2010 decennial census. For the 2015 to 2021 period, we first check for state location in third party data acquired by the Census Bureau[5], but subsequently use state locations from MAF-ARF, ACS, and 2010 decennial data.

This approach to assigning last known state of residence improves upon prior work utilizing restricted-use Census Bureau data and allows the development of state-level excess mortality estimates that complement those released by the National Center for Health Statistics. Polyakova et al. (2021) examined excess all-cause mortality by state and race for April 2020 using the Numident linked to a variety of other sources but relied on the MAF-ARF to determine residential locations. We extend this general approach to supplement MAF-ARF locations with those from the 2010 decennial census, ACS, and third-party data, thereby increasing location coverage rates for the Numident universe. The resulting state-level statistics serve as a complement to those produced by the NCHS; our estimates capture excess mortality in the state of last known residence, while NCHS estimates detail excess mortality in the state of death noted on death certificates.[6]

Data Linkage and Sample Restrictions

The universe of individuals ever issued an SSN in the Census Numident is linked to the other data sources discussed above and restricted to an analytical universe as follows (see also Appendix 1). All individual-level linkages across data sources are made using anonymous Protected Identification Keys (PIKs) assigned using the Person Identification Validation System

[5] Data use agreements prohibit the explicit naming of these sources.
[6] See https://www.cdc.gov/nchs/nvss/vsrr/covid19/tech_notes.htm.

(PVS) software developed by the U.S. Census Bureau (Wagner and Layne 2014).[7] We first restrict the universe of all SSN-holders to the 421.2 million individuals alive as of January 1, 2010. Analysis is then limited to individuals with non-missing date of birth, sex, and race/ethnicity information, most of which were not enumerated in the 2010 decennial census and just over one-third of which were born in 2010 or later, leaving 294.9 million individuals. Because they were not enumerated in 2010 and are poorly covered in other datasets, we also remove an additional 3 million individuals who were born in 2010 or later. Finally, because death reports in the Numident are less complete prior to 1960 (Finlay and Genadek 2021) and deaths are uncommon among children, we restrict analysis to those at least 15 years of age and under 100 years of age at the start of any given month. In an average month between April 2010 and March 2021, this step removes 32.6 million additional individuals. Note that, although not all person-year observations can successfully be assigned a state location, we retain these observations in our analysis and, where applicable, simply report an additional statistic for those missing a state location. The final analytical universe consists of 259.3 million unique individuals yielding 2,377 million person-year observations in the April 2010 to March 2020 reference period and 248 million person-year observations from the April 2020 to March 2021 COVID-19 pandemic period.

III.B Methods

To gauge the impact of COVID-19 on mortality, we estimate a measure of *excess all-cause mortality* – the share of deaths from any cause we actually observe during the pandemic exceeding the number of deaths we would expect given observed mortality trends in the recent past. Measuring excess all-cause mortality during the COVID-19 pandemic requires the estimation of an expected mortality rate which is likely to have prevailed in the counterfactual absence of the pandemic. Methods for estimating this hypothetical mortality rate are varied, but follow a common intuition – namely that, in the absence of COVID-19, mortality trends for the recent past would have continued more or less unchanged. To illustrate the range of methods, consider the following three papers, each of which has yielded important insights into excess mortality since the onset of the pandemic in the United States in April of 2020. First, Luck et al. (2021) simply compare age-standardized death rates from 2020 to those from 2019. Second, the NCHS uses the Farrington surveillance algorithm to quantify larger than expected increases in deaths given observed trends since 2013.[8] Third, in an analysis of excess mortality at the start of the pandemic, Polyakova et al. (2021) use linear regression to model changes in the slope of race-specific mortality trends for April 2020 relative to trends in April of 2011 through 2019.

Our approach to estimating expected mortality in the counterfactual absence of the pandemic is similar in principle to these methods, but, after testing multiple approaches (see Appendix 2 for a discussion), we adopt a regression strategy that inherently reflects the non-negative, count-based nature of the underlying death data. Specifically, to estimate expected all-

[7] It should be noted that, though all individuals in the Numident file are assigned a PIK, rates of PIK assignment in other data sets used in this analysis are lower. For example, the PIK rate is 90 percent for the 2010 decennial census (Rastogi and O'Hara 2012). When SSNs are not available (as is commonly the case in decennial and survey responses), the PVS process relies on names, dates of birth, and other Personally Identifiable Information to probabilistically assign a PIK. We do not attempt to adjust for any non-random variation in the likelihood of PIK assignment (Bond et al. 2014). Strictly speaking, then, this analysis is representative of the U.S. population with an SSN who also received a PIK in at least one other dataset (such as a decennial census or the ACS) capturing their racial/ethnic identification.

[8] See https://www.cdc.gov/nchs/nvss/vsrr/covid19/tech_notes.htm.

cause mortality in the counterfactual absence of the COVID-19 pandemic, we first predict group-specific (i.e., by age, sex, race/ethnicity, state, month, and year) death counts for the pre-pandemic reference period using negative binomial regression with a population exposure term (or, equivalently, a logged population offset term). We then use the estimated regression equation from this model to predict expected group-specific death counts (with 95% confidence intervals) for the COVID-19 era. To account for differences in population size across groups, we express these predicted death counts as group-specific mortality per 10,000 person-months. Finally, we calculate excess all-cause mortality as the difference between observed and predicted mortality rates in the COVID-19 era.

A note on time periods used in estimation and the presentation of results

As hinted at above in our discussion of data linkage and sample restrictions, we do not use standard calendar years for estimation or the presentation of results. Rather, we attempt to compare as directly as possible the first full year of observed COVID-19 era mortality to the mortality rate that would have likely prevailed in the same period in the hypothetical absence of COVID-19. To do this, we designate April 1, 2020 as the start of the pandemic period for all analyses,[9] and we observe all-cause mortality for the following 12 months through March 31, 2021.[10] Though sometimes noted explicitly, we commonly refer to this April 1, 2020 to March 31, 2021 period as "2020". The 10-year reference period used to model expected mortality for the COVID-19 era, then, runs from April 1, 2010 to March 31, 2020.[11]

Figure 1 shows monthly mortality per 10,000 for the pre-COVID-19 (desaturated blue lines) and COVID-19 (solid blue line) periods used throughout. Mortality rates throughout the COVID-19 era are clearly elevated relative to rates for the previous ten years, though periodic peaks and troughs occur over the course of the pandemic. These peaks form three distinct "waves" for which we aggregate statistics in some of the analyses that follow.[12] Wave 1, starting in April and ending in June, represents the start of the pandemic in 2020 and peaked at 12 deaths per 10,000. A small peak in mortality at 10.5 per 10,000 also occurs in July and August of 2020, subsiding in September to constitute Wave 2. Finally, the most prolonged and deadly period from October 2020 through March 2021 – coinciding with both the rise of the COVID-19 Delta variant and the annual influenza season – constitutes Wave 3, which peaked in January 2021 at over 14 deaths per 10,000.

A brief overview of our analytical universe and excess mortality methods

Table 1 reports *unadjusted* mortality rates for our linked analytical universe for the pre-COVID-19 (April 1, 2010 to March 31, 2020) and COVID-19 eras (April 1, 2020 to March 31, 2021). Broadly speaking, our data for the pre-COVID period are consistent with the literature on

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[9] NCHS estimates show signs of significant increases in mortality as early as the week ending on March 28, 2020. As such, our choice of April 1, 2020 as the start of the COVID-19 era is somewhat conservative and may slightly underestimate excess mortality at the start of the pandemic, particularly for any population subgroups disproportionately impacted in initial waves.

[10] NCHS data suggest that excess mortality dropped below upper bound estimates of expected mortality for the first time since the start of the pandemic in the week ending on March 13, 2021.

[11] See Appendix 2 for a discussion of our choice of reference period and the impact of the reference period length on results.

[12] Our delineation of distinct pandemic waves is intended to aid in the discussion of broader trends and may not conform with more rigorous attempts to formalize definitions for expositional or comparative purposes (Solis et al. 2020; Zhang et al. 2021).

mortality gaps by sex, age, and race/ethnicity (Arias et al. 2021; Bassett et al. 2020; Goldstein and Atherwood 2020; Luck et al. 2021; Polyakova et al. 2021; Rossen et al. 2021; Solis et al. 2020). Pre-pandemic mortality is higher for males (9.3 per 10,000) than for females (8.7 per 10,000) and increases steadily with age. Moreover, unadjusted racial/ethnic gaps in Table 1 are also consistent with gaps reported in the morality literature. Disaggregated mortality trends in the COVID-19 era are also quite consistent with prior reports. Table 1 provides some early descriptive evidence that unadjusted all-cause mortality increased more among men, NH AIAN alone, Hispanic, and NH Black alone individuals, and among those over age 65. But descriptive results by age in Table 1 also highlight a weakness of excess mortality statistics relying on an estimate of expected mortality derived from an average over some prior period. Averages may be a poor indicator of expected mortality if the distribution of individuals across age categories changes. Because the population is simultaneously aging and, on average, living longer in the pre-COVID era, the descriptive results in Table 1 suggest that mortality rates for those 80 and older *declined* during the pandemic. As we show below, this is certainly not the case, and this example serves to highlight the importance of correctly modeling expected mortality to assess the impacts of the pandemic.

Figure 2 depicts the results from a simplified version of our excess mortality estimation technique. Specifically, this figure shows observed (circles) and expected (line) mortality for the April 2010 to March 2020 period at the national level, with a 95% confidence interval around expected values shown as the shaded region around the trend line. As also reported in Table 1, Figure 2 shows a steady increase in observed mortality consistent with the aging of the U.S. population. Were this steady increase in mortality to have continued in the absence of the COVID-19 pandemic, our model predicts an expected mortality rate in 2020 (April 2020 to March 2021) of 9.3 (+/- 0.1) per 10,000 person-months (PM). Due to the COVID-19 pandemic and related changes in all-cause mortality, however, the observed mortality rate in 2020 was 11.1 per 10,000 PM. Throughout, we refer to the difference between the expected value obtained from our model and the mortality observed as excess all-cause mortality. As depicted in Figure 1, then, we estimate an excess mortality rate in the United States of 1.8 per 10,000 PM (or, multiplying by 120, 216 per 100,000 person-years) – a nearly 20 percent increase over the expected 2020 mortality rate – in the first full year of the COVID-19 pandemic.

IV. Results

Unadjusted Excess All-Cause Mortality

Unadjusted estimates presented in Table 2 confirm that excess all-cause mortality in the first full year of the pandemic was unevenly distributed across the U.S. population. Observed mortality rates were 2.1 per 10,000 person-months (PM) (or 21.4 percent) higher than expected for males, but 1.6 per 10,000 PM (18.0 percent) higher than expected for females. While observed mortality for all age groups fell outside the 95 percent confidence interval around expected values and increased monotonically with age, excess mortality among those under 40 was relatively low, peaking at 0.3 per 10,000 PM for the 35-39 age group. However, excess mortality exceeded 1 per 10,000 PM for those age 55 and above and 4 per 10,000 PM among those 70 and older. Unadjusted results by race/ethnicity are, broadly speaking, consistent with prior studies (Arias et al. 2021; Bassett et al. 2020; Goldstein and Atherwood 2020; Luck et al. 2021; Polyakova et al. 2021; Rossen et al. 2021; Solis et al. 2020) finding relatively low excess mortality among NH White alone (1.6 per 10,000 PM; 14.8 percent higher than expected) and

NH Asian alone individuals (1.2 per 10,000 PM; 25.7 percent higher than expected), but relatively high excess mortality among NH AIAN alone (3.6 per 10,000 PM; 36.5 percent higher than expected), NH Black alone (2.7 per 10,000 PM; 32.0 percent higher than expected), and Hispanic (2.3 per 10,000 PM; 47.5 percent higher than expected) individuals.

Adjusted Excess All-Cause Mortality

Because excess mortality is concentrated among those over age 65, and because the racial/ethnic groups hit hardest by the pandemic are younger, on average, than NH Whites, the unadjusted excess mortality estimates reported in Table 2 serve as a conservative, lower-bound estimate of the pandemic's disproportionate impact on minority groups. Table 3 reports age- and sex-adjusted estimates that facilitate a more direct comparison of excess mortality across racial/ethnic groups. To make these adjustments, we apply unadjusted age-, sex-, and race/ethnicity-specific mortality rates to a single standard population distribution – in this case, the national population distribution. The resulting estimates tell us how excess mortality differs by race/ethnicity, "controlling for" differences in the distribution of populations across age and sex groups.

As expected, after making age and sex adjustments, racial/ethnic gaps in excess all-cause mortality widen (Table 3). Adjusted excess mortality is lowest for NH White alone individuals (1.4 per 10,000 PM), followed by NH Asian alone (1.5 per 10,000 PM), NH Multiple race (1.7 per 10,000 PM), NH NHPI alone (2.2 per 10,000 PM), NH SOR alone (2.5 per 10,000 PM) individuals. But adjusted excess mortality among NH AIAN alone (4.7 per 10,000 PM), Hispanic (3.6 per 10,000 PM), and NH Black alone (3.5 per 10,000 PM) individuals far exceeds levels among other groups. In proportional terms (that is, normalized by race/ethnicity-specific age- and sex-adjusted expected mortality) that take into account pre-pandemic racial/ethnic differences in mortality rates, adjusted excess mortality in the first year of the pandemic was greatest for Hispanic individuals (49.1 percent higher than expected), followed by NH SOR alone (35.1 percent), NH AIAN alone (34.6 percent), NH Black alone (31.4 percent), NH Asian alone (29.0 percent), NH NHPI alone (20.4 percent), NH multiple race (17.3 percent), and NH White alone (14.6 percent) individuals.

While these findings are broadly consistent with prior studies, our results differ with respect to the size of race/ethnicity specific excess mortality estimates and assessments of the relative severity of the pandemic's impacts by race/ethnicity. For example, we find that excess mortality in the first year of the pandemic was greatest among NH AIAN alone individuals, at 4.4 per 10,000 PM more deaths than expected. Despite adopting a conservative modeling strategy and reference period for estimating expected mortality (see Appendix 2), this is the highest estimate of excess mortality among U.S. indigenous populations that we have come across in the literature, likely reflecting the high rates of AIAN misclassification on death certificates (Arias et al. 2008, 2016). We also report estimates for NH SOR alone and NH Multiple race individuals, which are few and far between in the literature thus far (but see Polyakova et al. 2021, who combine estimates for NH SOR alone and NH Multiple race groups). As such, these differences may reflect improvements in the measurement of racial/ethnic identification and the degree of detail with which we can report racial/ethnic categories – both of which are afforded by our use of decennial and ACS self- and proxy-responses.

But differences between our results for the first year of the pandemic and those from prior studies also reflect differences in the temporal scope of the underlying data used. As shown in Figure 3, which plots monthly age-adjusted excess mortality by sex and race/ethnicity, there is substantial racial/ethnic variation in excess mortality as the first year of the pandemic unfolds, with group-specific peaks in excess mortality occurring at different times throughout the year. At the start of the pandemic in April 2020, though all racial/ethnic and sex groups experienced excess mortality, rates were highest for male NH Black alone individuals (10.2 per 10,000 PM), NH SOR race individuals (9.9 per 10,000 PM), and Hispanics (5.7 per 10,000 PM). For NH Black alone and NH SOR race individuals, excess mortality peaked in April 2020, and we find that our estimates of excess mortality for these groups are consistent with (though higher than) other studies of excess mortality in the initial stages of the pandemic (e.g., Polyakova, et al. 2021). As with the initial onset of the pandemic, all racial/ethnic groups experienced a second surge in excess mortality around July and August of 2020. This mid-year excess mortality wave was largest for male Hispanics (5.8 per 10,000 PM), followed by NH AIANs (4.8 per 10,000 PM) and male NH Blacks (4.0 per 10,000 PM), but this surge did not represent peak excess mortality for any racial/ethnic or sex group. Instead, for all groups except NH Black alone and NH SOR race individuals, peak excess mortality occurred in December of 2020 or January of 2021 and was largest for NH AIAN alone males (12.3 per 10,000 PM), Hispanic males (9.8 per 10,000 PM), and NH NHPI alone males (7.7 per 10,000 PM).

Taken together, the racial/ethnic and temporal trends we report here are broadly consistent with those reported by Rossen et al. (2021) using data through January of 2021, but we build upon their work by extending the analysis through March 2021 and facilitating granular insight into trends for racial/ethnic groups more difficult to capture using death certificate or aggregate state-level reports. For example, the novel estimates for NH SOR alone individuals shown in Figure 3 suggest that their pandemic-era mortality experiences may have been closely tied to the experiences of NH Black alone individuals, whereby excess mortality peaked in April 2020, fell during the summer wave, and rose again December/January. Trends for NH Multiple race individuals, however, more closely resemble those of NH Asian alone and NH White alone individuals, in terms of both the timing and scale of peaks in excess mortality over the first year.

Age-, Sex-, and Race/Ethnicity-Specific Excess All-Cause Mortality

While the adjusted results presented above allow for direct comparisons of excess mortality across racial/ethnic groups, they – by design – mask racial/ethnic differences in excess mortality at specific ages. Prior research has emphasized this point by quantifying pandemic era mortality in terms of changes in life expectancy at birth (Andrasfay and Goldman 2020; Woolf et al. 2021) or years of potential life lost (Bassett et al. 2020), measures which amplify the impact of excess mortality at younger ages disproportionately occurring among racial/ethnic minority groups. But these summary measures of mortality carry implicit assumptions that complicate their interpretation: period life expectancy measures presume that a hypothetical cohort of individuals will experience pandemic-era mortality rates for the foreseeable future, while years of potential life lost measures require assumptions about the number of years an individual who died during the pandemic might have lived in the absence of it.

We leverage the power afforded by our population-level administrative and Census Bureau data to side-step these issues and, instead, simply report age-, sex-, and race/ethnicity-specific excess mortality rates for the first full year of the pandemic. Figure 4 reports these group-specific excess mortality rates, allowing direct comparisons of excess mortality across the age distribution. Figure 5 expresses these group-specific excess mortality rates proportionally – that is, normalized by the expected mortality rate for each group. The estimates plotted in these two figures are also included in Appendix Table 3.

The group-specific estimates of excess mortality in Figure 4 add nuance to the unadjusted estimates shown in Table 2. With respect to differences by sex, group-specific estimates reveal that the lower rate of excess mortality for females, in general, reflects not only lower excess mortality than men at virtually every age, but also lower mortality particularly in mid- and late-life. This pattern holds across all race/ethnicity groups, suggesting that pandemic era excess mortality gaps by sex may be closely tied to pre-existing sex gaps in mortality (Table 1). With respect to racial/ethnic differences in excess mortality across the age distribution, Figure 4 shows a clear uptick in excess mortality in prime working-age (25 to 54) populations among NH AIAN alone men and women, Hispanic men, NH Black alone men, and NH NHPI alone men not seen amongst their NH White alone and NH Asian alone counterparts. But substantial racial/ethnic differences in excess mortality are also apparent within specific 10-year age groups. We estimate excess mortality among those age 75 to 84, for example, at 8.9 and 5.6 per 10,000 PM for NH White alone men and women, respectively, but these estimates are far surpassed by rates for NH AIAN alone men and women at 20.3 and 15.3 per 10,000 PM, respectively.

If excess mortality during the pandemic were merely a reflection of pre-existing disparities, we would expect the group-specific rates in Figure 4 to be roughly equal when normalized by pre-pandemic rates. In other words, while absolute excess mortality might differ, we would expect excess mortality proportional to established trends. As shown in Figure 5, however, we find substantial variation in proportional excess mortality, particularly across racial/ethnic groups (see also Tables 2 and 3). While proportional excess mortality for male and female NH White alone individuals never exceeds 20 percent across the age distribution (with the sole exception of men ages 75 to 84, at 20.2 percent), proportional excess mortality for NH Black alone men and women never dips below 20 percent and, for Hispanic men ages 45 to 84, exceeds 60 percent. Proportional excess mortality also differs sharply within race/ethnicity groups across the age distribution. Among NH AIAN alone and Hispanic individuals, for example, Figure 5 tracks an inverted U-shape across the age distribution, with much higher proportional excess mortality among men and women of prime working age than those at younger and retirement ages. As such, the group-specific mortality trends shown in Figure 4, while to some extent a sign and symptom of persistent gaps in mortality in the United States prior to the pandemic, are also reflective of pandemic era pressures which exacerbated existing disparities in new ways both within and across racial/ethnic groups.

Temporal-Spatial Variation in Excess All-Cause Mortality

As shown in Figure 1, excess all-cause mortality varied substantially over the course of the first year of the pandemic, but this temporal variation also had geographic corollaries. Figure 6 plots age- and sex-adjusted excess all-cause mortality by state for four periods (see also Appendix 4). Excess mortality for the entire April 1, 2020 to March 31, 2021 period is shown in the upper-left panel, while the remaining three panels show excess mortality for April 1, 2020 to June 31, 2020 (Wave 1, upper-right), July 1, 2020 to September 30, 2020 (Wave 2, lower-left), and October 1, 2020 to March 31, 2021 (Wave 3, lower-right). Note that choropleth scales differ across panels in Figure 6 in order to emphasize interstate variation in excess mortality within waves.

New York and New Jersey were hit particularly hard in the initial wave of the pandemic, and both states saw excess all-cause mortality rates of approximately 6 per 10,000. High excess mortality was seen in New York-adjacent Massachusetts and Connecticut (3.7 per 10,000 PM), but also in states like Louisiana (3 per 10,000 PM), Illinois, and Michigan (2.4 per 10,000 PM each), as well as in Washington, D.C. (5.4 per 10,000 PM).

The second wave of the pandemic, though less severe than the first, shifted the geographic distribution of excess mortality from the Northeast to the Deep South and Southwest. Mississippi (3.7 per 10,000 PM), Texas (3.5 per 10,000 PM), and Louisiana (3.2 per 10,000 PM) experienced the highest excess mortality in this period, but excess mortality was concentrated in other Deep South states like Georgia (2.8 per 10,000 PM), Alabama, and South Carolina (3 per 10,000 PM each). The second wave also saw an initial increase in excess mortality in the Southwest, including Arizona (2.6 per 10,000 PM), Nevada (2.2 per 10,000 PM), and California (1.6 per 10,000 PM).

Wave 3, the longest and most devastating period of the pandemic's first year, was also the most geographically dispersed wave, causing excess all-cause mortality in virtually all states. While excess mortality remained high in parts of the Deep South, like Alabama (3.4 PM) and Mississippi (3.1 PM), rates were highest in Oklahoma (3.7 PM) and excess mortality had increased substantially in Southwestern states like New Mexico (3.2 per 10,000 PM), South Dakota (3.2 per 10,000 PM), and California (2.6 per 10,000 PM), as well as Arkansas, Missouri, and states in the Ohio River Valley and Appalachian region.

Temporal-Spatial Variation in Racial/Ethnic Gaps in Excess All-Cause Mortality

There has been some speculation in the excess mortality literature about the possible influence of changes in the geographic dispersion of the pandemic on concomitant changes in racial/ethnic gaps in excess mortality (Gold et al. 2020; Kumar et al. 2021; Lawton et al. 2021). Specifically, changes in the Black-White and Hispanic-White excess mortality gaps are thought to be tied to the dispersal of the pandemic from large, densely populated metropolitan areas in the Northeast to smaller, less densely populated states in the South and West.

While national trends in adjusted excess all-cause mortality gaps offer some evidence in favor of this geographic dispersion hypothesis, they also suggest that geographic dispersion is only part of the story. Figure 7 plots the monthly racial/ethnic gaps in excess mortality relative to NH White alone individuals for the three groups with the largest excess all-cause mortality rates in the first year of the pandemic. Trends in the Hispanic-White gap, which peaks for both males and females in January 2021 at 7.0 and 3.7 per 10,000 PM, respectively, provide little evidence in favor of the geographic dispersal hypothesis. The Hispanic-White gap mirrors overall trends in excess mortality – that is, the gaps wax and wane in lockstep with peaks shown in Figure 1 – rather than more strictly tracking the dispersal of the pandemic in Waves 2 and 3 to the South and West where Hispanic populations are disproportionately located. Trends in the Black-White gap provide at least some evidence for the geographic dispersal hypothesis, as the gap is largest (8.4 and 6.0 per 10,000 PM for males and females, respectively) at the start of the pandemic in April 2020 when NH Black alone excess mortality peaked (Figure 3). The Black-White gap declines substantially after Wave 1, but this decline is not monotonic, and clear Wave 2 and 3 peaks are apparent in the Black-White gaps shown in Figure 7. Perhaps the strongest evidence in favor of the geographic dispersal hypothesis is found in the AIAN-White gap shown in Figure 7. Here, the AIAN-White gap appears to track closely the dispersal of excess mortality from large population centers in the Northeast in Wave 1, to states in the South and West with larger AIAN populations in Wave 2 (e.g., AZ), to a larger collection of states (e.g., OK, NM, and SD) with sizeable AIAN populations in Wave 3. The AIAN-White gap reached its peak in December of 2021 at 7.5 and 6.7 per 10,000 for males and females, respectively.

The national level trends shown in Figure 7 suggest that, regardless of where excess mortality is most heavily concentrated in the U.S. at any point in time, when excess mortality peaks, it impacts NH Black alone individuals more severely than their NH White alone counterparts. This finding is supported by Figure 8, which plots the state-level expected and observed Black-White mortality gaps by wave. Though the observed Black-White gaps in Wave 1 are much larger than expected in places like NY (11.7 per 10,000 PM), NJ (10.1 per 10,000 PM), and DC (12.9 per 10,000 PM), they are above expected levels in all but a handful of states (HI, ID, OR, and WV). By Waves 2 and 3, which saw the dispersion of the pandemic to states in the Deep South with large NH Black alone populations, excess mortality gaps (as indicated by the vertical distance between the dashed 45-degree line and individual points) are largest in MS and AR, but are, again, above expected levels (as indicated by the dashed 45-degree line) in all states. Taken together, the plots in Figure 8 suggest that, aside from the initial months of the pandemic which disproportionately impacted NH Black alone individuals in the NY and NJ area, pandemic-era mortality gaps are largely a continuation and exacerbation of entrenched mortality disparities across the United States.

Prior to the pandemic, the Hispanic-White mortality gap favored Hispanic individuals (Tables 1 and 2), but this national-level Hispanic mortality advantage disappeared during the pandemic. As shown in Figure 7, excess mortality was higher for Hispanic than for NH White alone individuals across the entirety of the first year of the pandemic, resulting in a complete closing of the age- and sex-adjusted Hispanic-White gap at the national level (Table 3). Figure 9 shows that this national-level shift in the Hispanic-White mortality gap was achieved via a shift in the mortality ratio in favor of NH White alone individuals across virtually all states. Nevertheless, there is substantial state-level heterogeneity in the extent to which the Hispanic-White mortality gap was maintained, closed, or reversed. As with NH Black alone individuals, Hispanics were hit much harder than NH White alone individuals in Wave 1 of the pandemic, resulting in extreme reversals of the Hispanic-White gaps in places like NY (from an expected gap of 1.5 per 10,000 PM in favor of Hispanics to an observed gap of 7.3 per 10,000 PM in favor of NH Whites) and NJ (from an expected gap of 1.9 per 10,000 PM in favor of Hispanics to an observed gap of 4.7 per 10,000 PM in favor of NH Whites), as well as more modest reversals in states across the country (such as PA, IL, IA, WI). The mortality gap reversals for NY and NJ in Wave 1 were short-lived, however, and had returned to near-expected levels by Wave 2. Instead, Wave 2 saw reversals of the Hispanic-White mortality gap in places like TX, ID, and AZ that lasted through the rest of Wave 3. Though the pre-pandemic Hispanic mortality advantage weakened in all states, it did not reverse in all states. Across all of 2020, Hispanic individuals maintained a sizeable mortality advantage relative to NH White alone individuals in several states, including GA, VA, MD, FL, and NC. Nevertheless, the closing of the Hispanic-White mortality gap and the much higher Hispanic excess all-cause mortality rates at the national level suggest the presence of substantial racial/ethnic gaps in exposure to and treatment for COVID-19 that are far surpassed by any shifts attributable to temporal-spatial variation in the pandemic's first year.

V. Discussion and Conclusion

Prior research on the impacts of the COVID-19 pandemic in the United States has highlighted substantial sociodemographic and geographic disparities in excess mortality but estimates of the size of these disparities have varied. Our primary goal in this paper was to address some of this variation – particularly variation rooted in aspects of data quality – by leveraging a restricted access dataset comprised of linked individual-level records from the SSA, the U.S Census Bureau, and several other administrative and third-party sources. These data, covering the universe of individuals ever issued an SSN, allow us to take both a broad view of the first full year of the pandemic and, at the same time, examine granular variation in excess all-cause mortality by age, sex, race/ethnicity, month, and state.

Nationally, we estimate an excess all-cause mortality rate of 1.8 per 10,000 person-months (or equivalently, multiplying by 120, 216 per 100,000 person-years) for the April 1, 2020 to March 31, 2021 period – the first full year of the COVID-19 pandemic. But this national figure masks substantial variation in excess mortality across demographic subgroups. Unadjusted excess all-cause mortality increases monotonically with age, is higher for males (2.1 per 10,000 PM) than females (1.6 per 10,000 PM) and is much higher for NH AIAN alone (3.6 per 10,000), NH Black alone (2.7 per 10,000 PM), and Hispanic (2.3 per 10,000) individuals than for NH White alone (1.6 per 10,000) individuals.

Adjusting for racial/ethnic differences in the distribution of the population across age and sex categories, however, reveals even larger differences in excess mortality during the pandemic. Adjusted excess mortality is lowest for NH White alone individuals (1.3 per 10,000 PM), followed by NH Asian alone (1.5 per 10,000 PM), NH Multiple race (1.7 per 10,000 PM), NH NHPI alone (2.1 per 10,000 PM), NH SOR alone (2.4 per 10,000 PM) individuals. But adjusted excess mortality among NH AIAN alone (4.4 per 10,000 PM), Hispanic (3.6 per 10,000 PM), and NH Black alone (3.5 per 10,000 PM) individuals far exceeds levels among other groups. Proportionally speaking, however, Hispanic individuals – who had relatively low pre-pandemic mortality rates – saw the largest increases in mortality of any group, nearly 50 percent higher than expected given past trends.

Estimates of monthly excess all-cause mortality for detailed age-, sex-, and race/ethnicity-specific groups revealed even further racial/ethnic variation in mortality trends over the life course. While excess mortality for NH White alone and NH Asian alone individuals is limited primarily to those 65 and older, we find evidence of substantial increases in excess mortality among NH AIAN alone, Hispanic, and NH Black alone adults (and men, especially) of prime working age. Broadly speaking, this finding is consistent with prior work showing that racial/ethnic gaps in excess mortality may be rooted in differential exposure to COVID-19 at work.

Though this work offers novel and granular insights into the effects of the pandemic in its first year, it is not without its limitations. First, because we lack cause of death information, we estimate excess mortality from all causes throughout. While this does allow us to gauge the overall impact of the pandemic on mortality, it hinders our ability to distinguish the direct impact of COVID-19, specifically, from the indirect impacts (whether positive or negative) of pandemic-era changes in deaths from drug/alcohol abuse, accidental deaths, homicides, and other causes (e.g., Luck et al. 2021). It should be noted that the all-cause mortality measures used here also mask any racial/ethnic variation in the share of excess mortality due to COVID-19 versus other causes. Second, because the SSA Numident serves as the backbone of our linked data, our analysis is limited throughout to individuals assigned an SSN. As such, we systematically miss the mortality of the population of individuals living in the United States who do not have an SSN, which may have a disproportionate impact on mortality estimates of racial/ethnic groups (e.g., Hispanics, NH Asians) with larger immigrant shares. To the extent that excess mortality is higher among those without an SSN (Clark et al. 2020), the estimates of excess mortality presented here for these groups may serve as conservative, lower-bound estimates. Third, in addition to restricting to individuals with an SSN, our analysis is also limited to those with a non-missing race/ethnicity response on a decennial census or the American Community Survey. The impact of this restriction, however, results primarily in our inability to provide excess mortality estimates for those born after the 2010 census, a group for whom excess mortality during the pandemic has been low. Fourth, though we offer more detailed estimates of excess mortality by race/ethnicity than are typically available, our aggregation of all Hispanic individuals into a single category ignores substantial heterogeneity within this group. An important step in future work might be to consider variation within those self-identifying as Hispanic by nativity and, for foreign-born Hispanics, by country of birth.

Despite these limitations, our findings suggest that while some of the racial/ethnic gaps in excess all-cause mortality may be attributable to the geographic dispersion of the pandemic across the United States, temporal-spatial trends are more consistent with the notion that the social and economic determinants known to drive health disparities in the pre-pandemic era also operated during the pandemic to disproportionately increase mortality among disadvantaged racial/ethnic minority groups. Properly understanding the origin and persistence of racial/ethnic gaps in mortality requires accurate and detailed estimates of those gaps. Though adjudicating the precise mechanisms underpinning racial/ethnic disparities in excess all-cause mortality was beyond the scope of this paper, our hope is that the estimates presented here motivate and inform ongoing research on the causes and consequences of stark and persistent racial/ethnic mortality disparities in the United States.

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Tables & Figures

Table 1: Summary of Analytical Universe, April 2010 through March 2021

	Pre-COVID-19 (April 2010 to March 2020)			COVID-19 (April 2020 to March 2021)			Change	
	Deaths (% of Total)	Person-Months (% of Total)	Deaths per 10,000 Person-Months	Deaths (% of Total)	Person-Months (% of Total)	Deaths per 10,000 Person-Months	Raw Increase	Percent Increase
Year*								
2010	9.3	9.5	8.8	--	--	--	--	--
2011	9.3	9.6	8.7	--	--	--	--	--
2012	9.7	9.7	8.9	--	--	--	--	--
2013	9.6	9.9	8.7	--	--	--	--	--
2014	10.0	10.0	9.0	--	--	--	--	--
2015	10.0	10.1	9.0	--	--	--	--	--
2016	10.3	10.2	9.1	--	--	--	--	--
2017	10.6	10.3	9.2	--	--	--	--	--
2018	10.4	10.3	9.1	--	--	--	--	--
2019	10.7	10.4	9.2	--	--	--	--	--
2020	--	--	--	100.0	100.0	11.1	--	--
Sex								
Females	49.7	51.3	8.7	47.9	51.1	10.4	1.7	19.7
Males	50.4	48.7	9.3	52.1	48.9	11.8	**2.6**	**27.6**
Race/Ethnicity								
Hispanic	6.6	13.5	4.4	9.2	14.4	7.1	**2.7**	**61.7**
NH White Alone	78.4	66.6	10.6	73.4	65.3	12.5	1.9	18.2
NH Black Alone	10.9	12.2	8.0	12.5	12.3	11.3	**3.2**	**40.3**
NH AIAN Alone	0.7	0.7	8.9	0.9	0.7	13.6	**4.7**	**52.8**
NH Asian Alone	2.2	5.0	4.1	2.7	5.0	6.1	2.0	**49.0**
NH NHPI Alone	0.1	0.2	6.1	0.1	0.2	8.4	**2.3**	**38.5**
NH SOR Alone	0.1	0.2	3.7	0.1	0.2	5.4	1.7	**45.4**
NH Multiple Race	1.0	1.8	5.0	1.1	2.0	6.2	1.1	22.8
Age Group								
15-19	0.4	8.2	0.4	0.3	7.2	0.5	0.1	17.7
20-24	0.7	8.6	0.7	0.6	7.8	0.9	0.2	23.6
25-29	0.9	8.6	0.9	0.9	8.2	1.2	0.3	**38.8**
30-34	1.0	8.3	1.1	1.1	8.2	1.6	0.5	**47.5**
35-39	1.1	7.9	1.3	1.3	7.9	1.9	0.6	**47.1**
40-44	1.5	8.0	1.7	1.5	7.4	2.3	0.6	**37.6**
45-49	2.4	8.5	2.5	2.1	7.4	3.1	0.6	**24.0**
50-54	3.8	8.9	3.9	3.2	7.9	4.5	0.6	15.6
55-59	5.6	8.6	5.9	5.1	8.5	6.7	0.8	14.4
60-64	7.3	7.5	8.7	7.5	8.2	10.2	1.5	16.7
65-69	8.7	6.0	13.0	9.2	7.0	14.6	1.7	12.7
70-74	9.9	4.3	20.6	11.4	5.7	22.1	1.5	7.2
75-79	11.4	2.9	35.1	12.4	3.8	36.1	1.0	2.9
80-84	13.6	1.9	64.0	13.2	2.4	60.7	-3.3	-5.1
85-99	31.8	1.7	163.0	30.1	2.3	144.4	-18.6	-11.4
Total (Deaths and PMs in millions)	25.37	28,250.00	9.0	3.30	2,971.00	11.1	2.1	23.6

*Years run April 1 to March 31.

Note: Column percentages are reported for single years and demographic subgroups. For emphasis, group-specific estimates of mortality change exceeding the national average are shown in bold.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

Table 2: Unadjusted Excess All-Cause Mortality by Sex, Age, and Race/Ethnicity, April 2020 through March 2021

	Mortality per 10,000 Person-Months, April 2020 through March 2021				
	Expected*	95% Confidence Interval*	Observed	Excess†	Excess as Proportion of Expected
Overall	9.3	+/- 0.11	11.1	1.8	19.7
Sex					
Females	8.8	+/- 0.12	10.4	1.6	18.0
Males	9.8	+/- 0.10	11.8	**2.1**	**21.4**
Race/Ethnicity					
Hispanic	4.8	+/- 0.06	7.1	**2.3**	**47.5**
NH White Alone	10.9	+/- 0.13	12.5	1.6	14.8
NH Black Alone	8.5	+/- 0.12	11.3	**2.7**	**32.0**
NH AIAN Alone	10.0	+/- 0.12	13.6	**3.6**	**36.5**
NH Asian Alone	4.8	+/- 0.06	6.1	1.2	**25.7**
NH NHPI Alone	6.9	+/- 0.14	8.4	1.5	**21.0**
NH SOR Alone	4.1	+/- 0.12	5.4	1.3	**32.6**
NH Multiple Race	5.3	+/- 0.09	6.2	0.9	17.5
Age Group					
15-19	0.4	+/- 0.01	0.5	0.1	18.5
20-24	0.8	+/- 0.04	0.9	0.1	16.3
25-29	1.1	+/- 0.06	1.2	0.2	15.5
30-34	1.3	+/- 0.06	1.6	0.2	17.3
35-39	1.6	+/- 0.04	1.9	0.3	**20.2**
40-44	1.8	+/- 0.04	2.3	0.5	**26.3**
45-49	2.4	+/- 0.04	3.1	0.7	**27.0**
50-54	3.7	+/- 0.05	4.5	0.8	**22.5**
55-59	5.7	+/- 0.09	6.7	1.0	18.4
60-64	8.5	+/- 0.06	10.2	1.7	**20.2**
65-69	11.9	+/- 0.14	14.6	**2.7**	**23.0**
70-74	18.0	+/- 0.15	22.1	**4.1**	**22.8**
75-79	29.2	+/- 0.39	36.1	**6.9**	**23.8**
80-84	50.0	+/- 0.59	60.7	**10.7**	**21.3**
85-99	129.2	+/- 4.35	144.4	**15.2**	11.8

* Expected mortality rates and 95% confidence intervals for April 2020 to March 2021 are estimated using the prediction equation from a negative binomial regression predicting deaths for April 2010 to March 2020 as a function of a linear year term (and for disaggregated rows a sex, race/ethnicity, or age term, as well as a year*sex, year*race/ethnicity, or year*age interaction) and a population exposure term.
†Excess mortality is the difference between the observed mortality rate and the expected mortality rate.
Note: For emphasis, group-specific values exceeding the national average are shown in bold.
Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

Table 3: Age- and Sex-Adjusted Excess All-Cause Mortality by Race/Ethnicity, April 2020 through March 2021

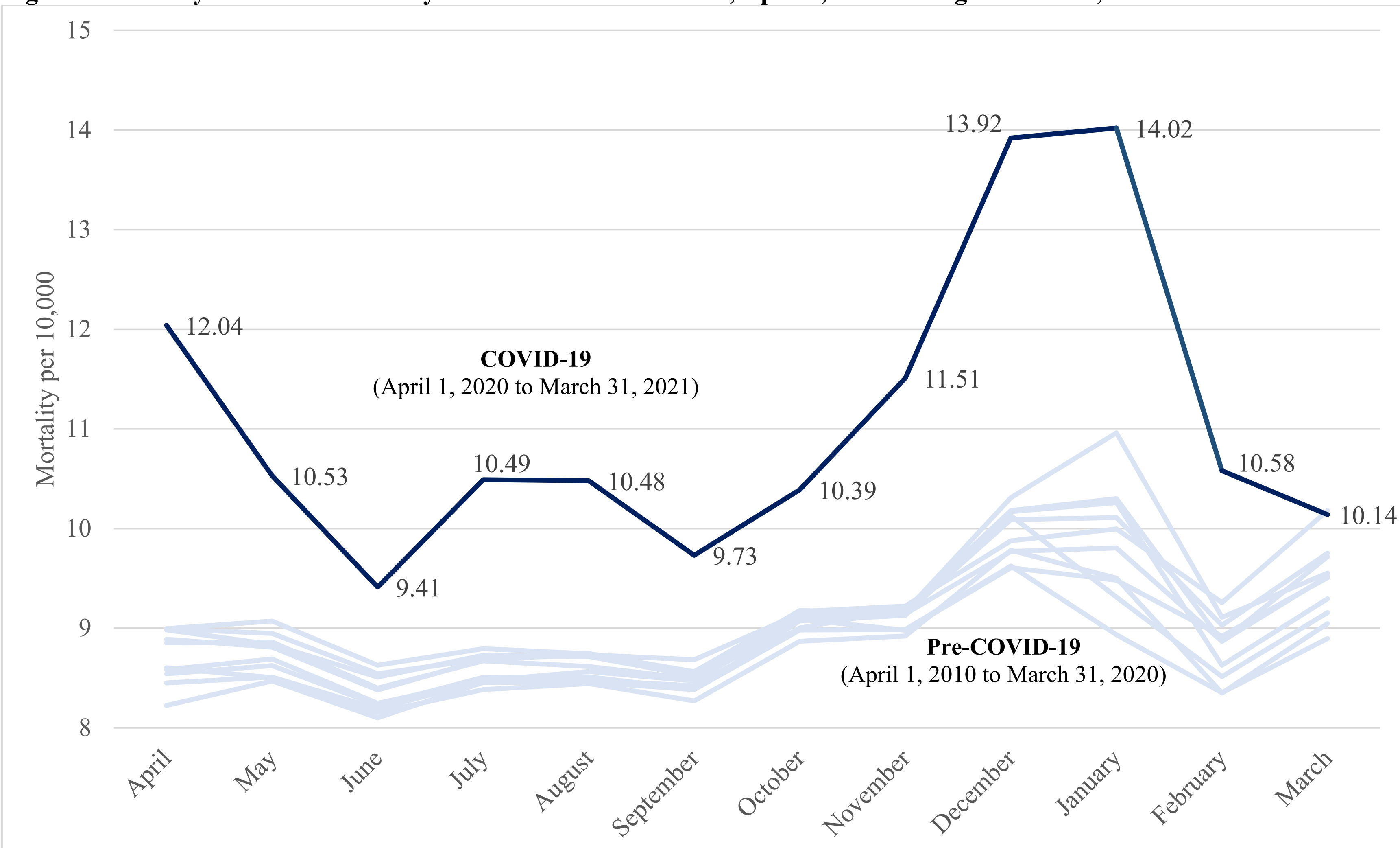
	Mortality per 10,000 Person-Months, April 2020 through March 2021				
Race/Ethnicity	Expected*	95% Confidence Interval*	Observed	Excess†	Excess as Proportion of Expected
Hispanic	7.3	+/- 0.09	10.9	3.6	49.1
NH White Alone	9.5	+/- 0.12	10.8	1.4	14.6
NH Black Alone	11.3	+/- 0.14	14.9	3.5	31.4
NH AIAN Alone	13.5	+/- 0.19	18.1	4.7	34.6
NH Asian Alone	5.0	+/- 0.06	6.5	1.5	29.0
NH NHPI Alone	10.7	+/- 0.32	12.9	2.2	20.4
NH SOR Alone	7.0	+/- 0.22	9.5	2.5	35.1
NH Multiple Race	10.0	+/- 0.18	11.8	1.7	17.3

* Age- and sex-adjusted expected mortality rates and 95% confidence intervals for April 2020 to March 2021 are estimated using the prediction equation from a negative binomial regression predicting population-standardized deaths for April 2010 to March 2020 as a function of a linear year term, a race/ethnicity term, a year*race/ethnicity interaction, and a population exposure term.

† Age- and sex-adjusted excess mortality is the difference between the observed population-standardized mortality rate and the expected population-standardized mortality rate.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

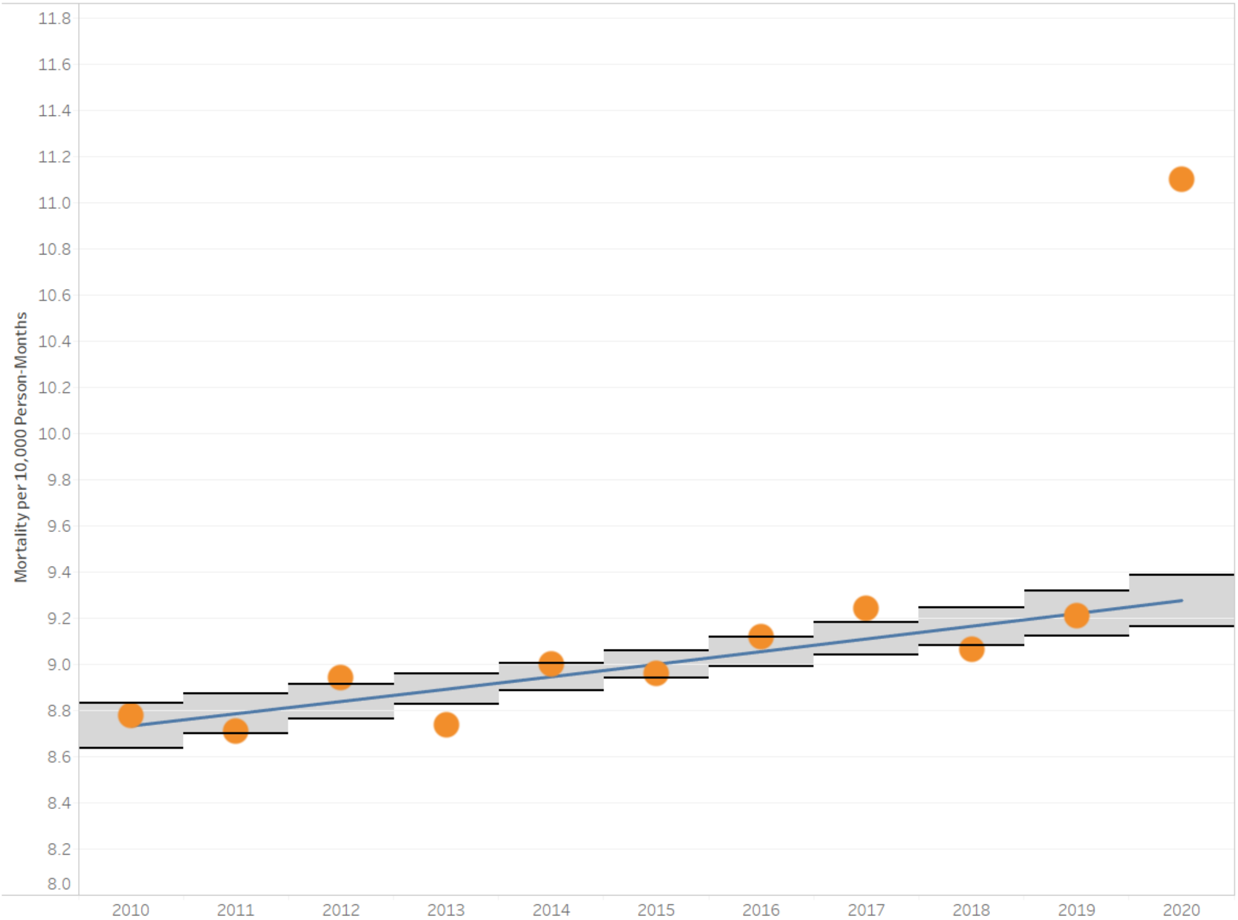
Figure 1: Monthly All-Cause Mortality Rates in the United States, April 1, 2010 through March 31, 2021



Note: Years run April 1 to March 31.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

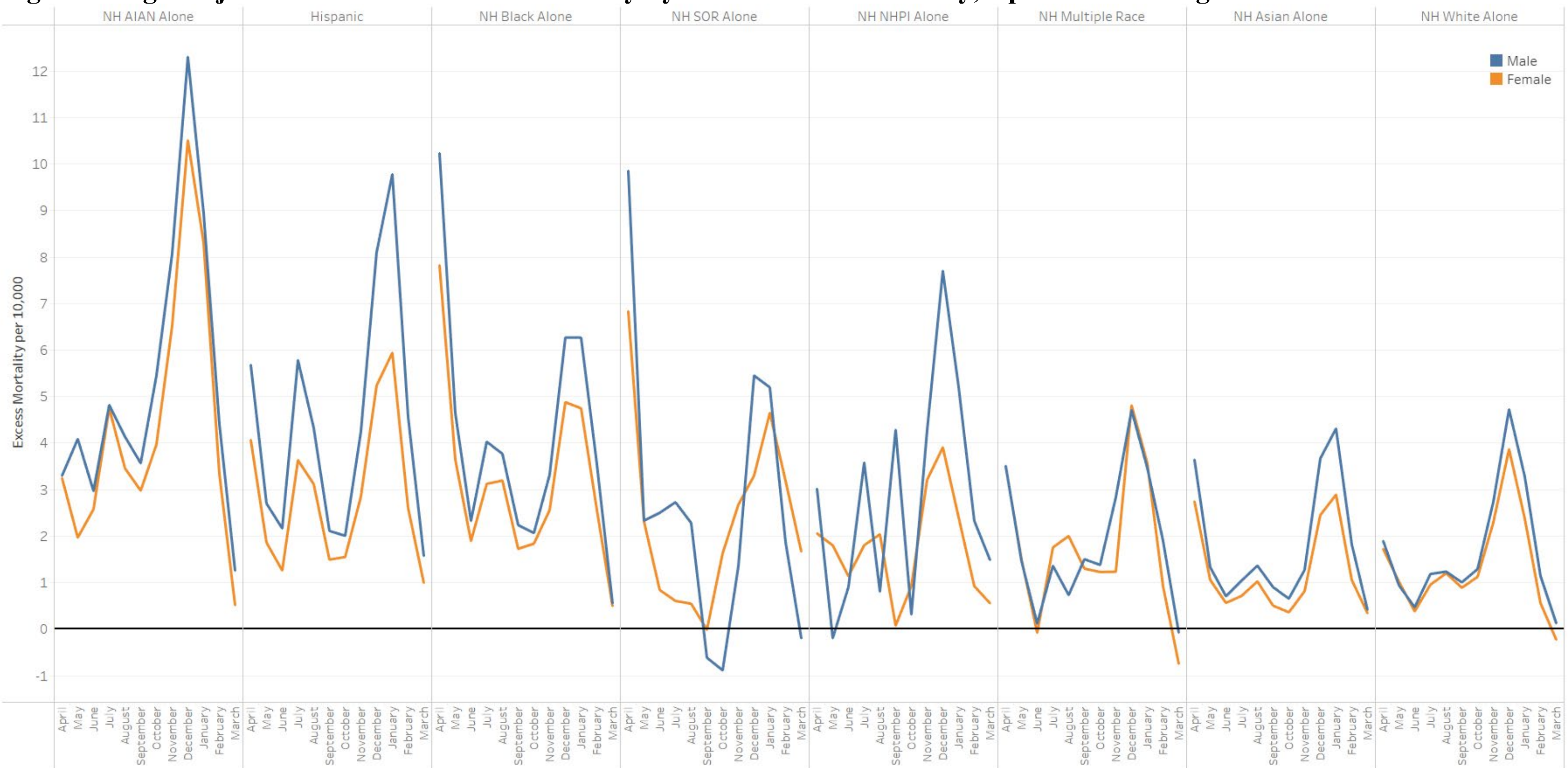
Figure 2: Observed and Expected All-Cause Mortality in the United States, April 2010 through March 2021



Note: Years run April 1 to March 31. Observed mortality rates are represented by orange circles. Expected mortality rates (blue trend line) and 95% confidence intervals (shaded region around trend line) for April 2020 to March 2021 estimated using the prediction equation from a negative binomial regression predicting deaths for April 2010 to March 2020 as a function of a linear year term and a population exposure term.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

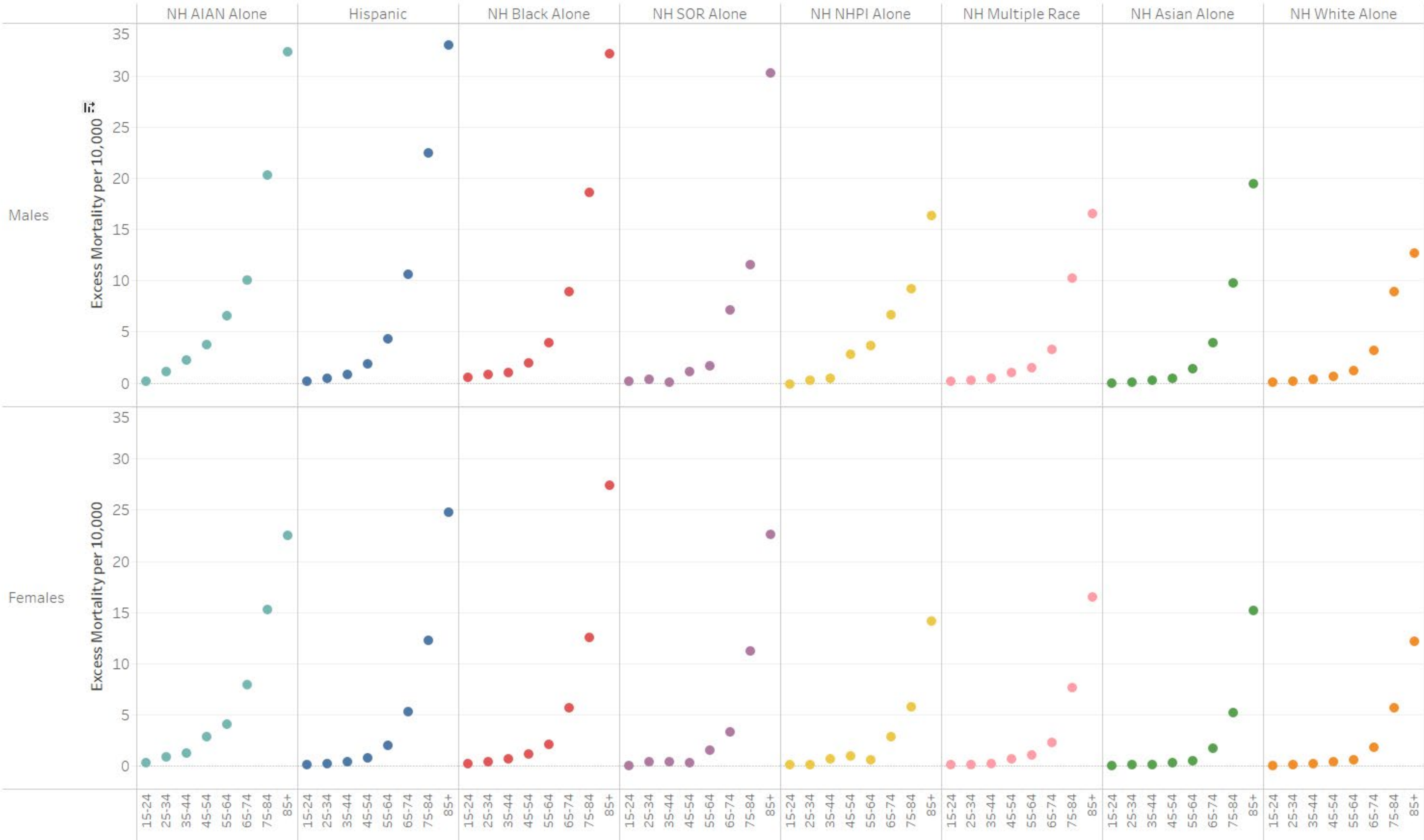
Figure 3: Age-Adjusted Excess All-Cause Mortality by Sex and Race/Ethnicity, April 2020 through March 2021



Note: Excess mortality is the difference between the observed population-standardized mortality rate and the expected population-standardized mortality rate. Expected mortality rates April 2020 to March 2021 estimated using the prediction equation from a negative binomial regression predicting age-adjusted sex- and race/ethnicity-specific deaths for April 2010 to March 2020 as a function of a linear year term, categorical month term, and a population exposure term.

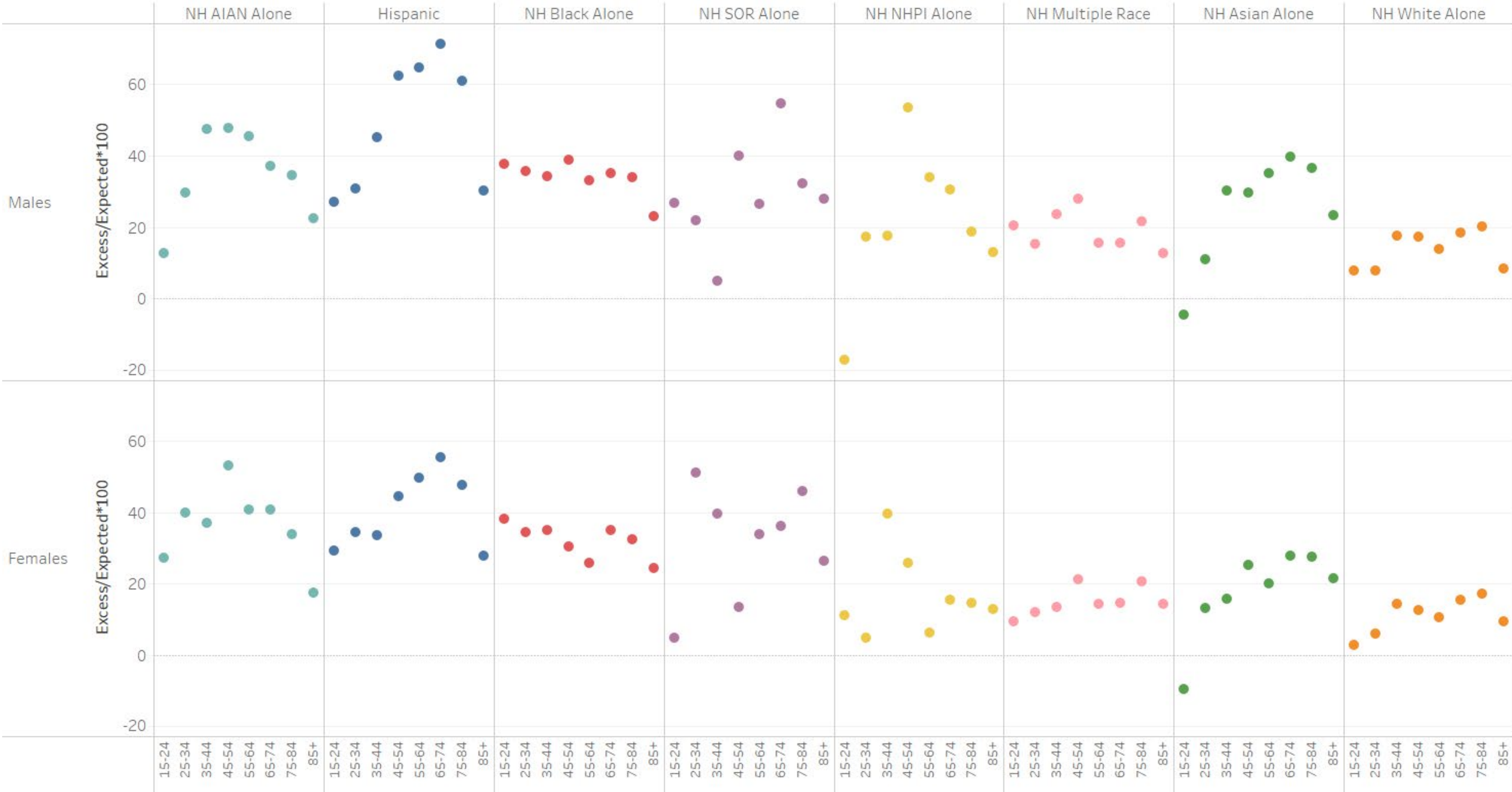
Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

Figure 4: Age-, Sex-, and Race/Ethnicity-Specific Excess All-Cause Mortality, April 2020 through March 2021



Note: Excess mortality is the difference between the observed mortality rate and the expected mortality rate for each age-, sex-, and race/ethnicity-specific population subgroup. Expected mortality rates April 2020 to March 2021 are estimated using the prediction equation from a negative binomial regression predicting age-, sex-, and race/ethnicity-specific deaths for April 2010 to March 2020 as a function of a linear year term, and a population exposure term. Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

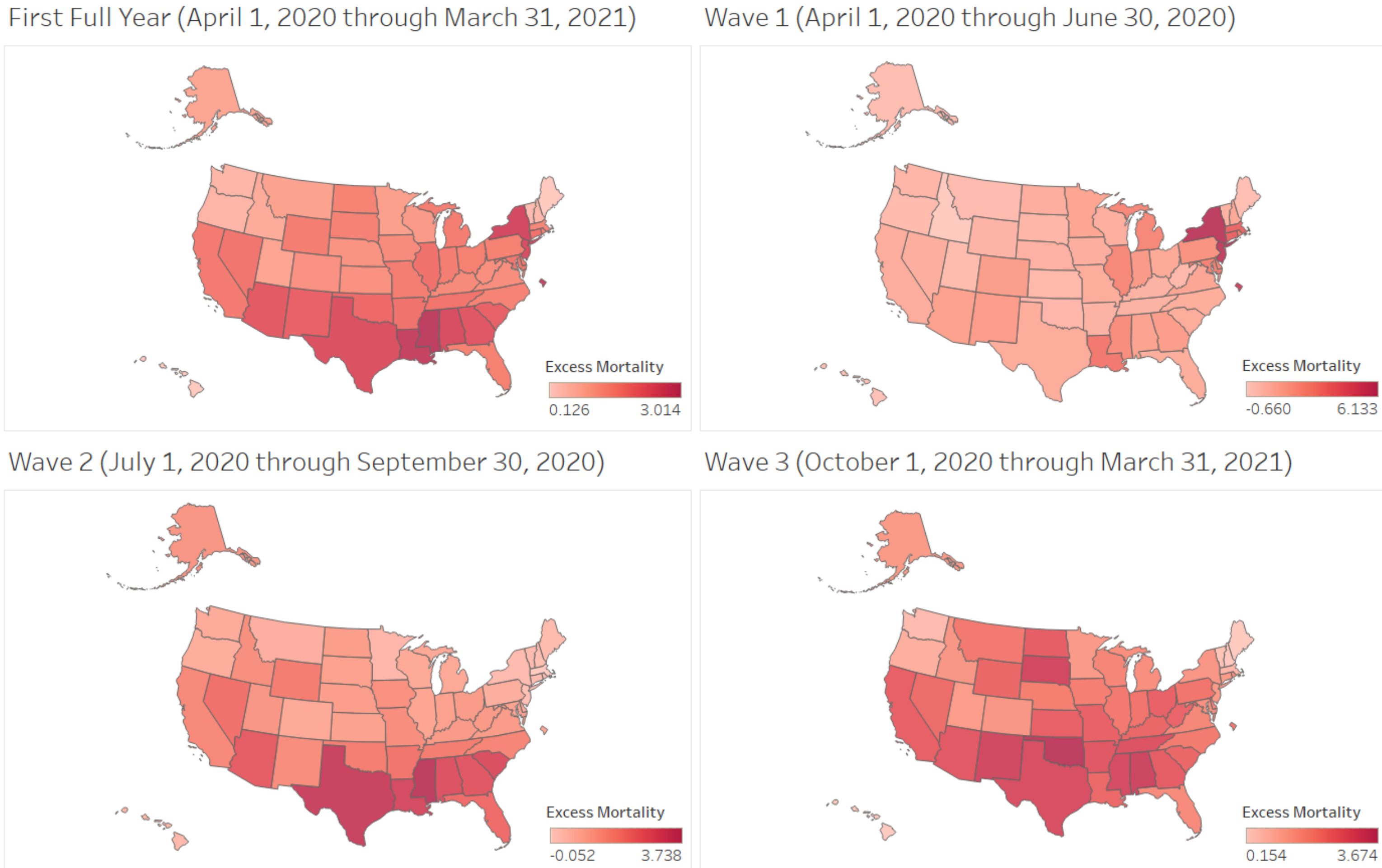
Figure 5: Age-, Sex-, and Race/Ethnicity-Specific Proportional Excess All-Cause Mortality, April 2020 through March 2021



Note: Proportional excess mortality is the difference between the observed mortality rate and the expected mortality rate normalized by the expected mortality rate for each age-, sex-, and race/ethnicity-specific population subgroup. Expected mortality rates April 2020 to March 2021 are estimated using the prediction equation from a negative binomial regression predicting age-, sex-, and race/ethnicity-specific deaths for April 2010 to March 2020 as a function of a linear year term, and a population exposure term.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

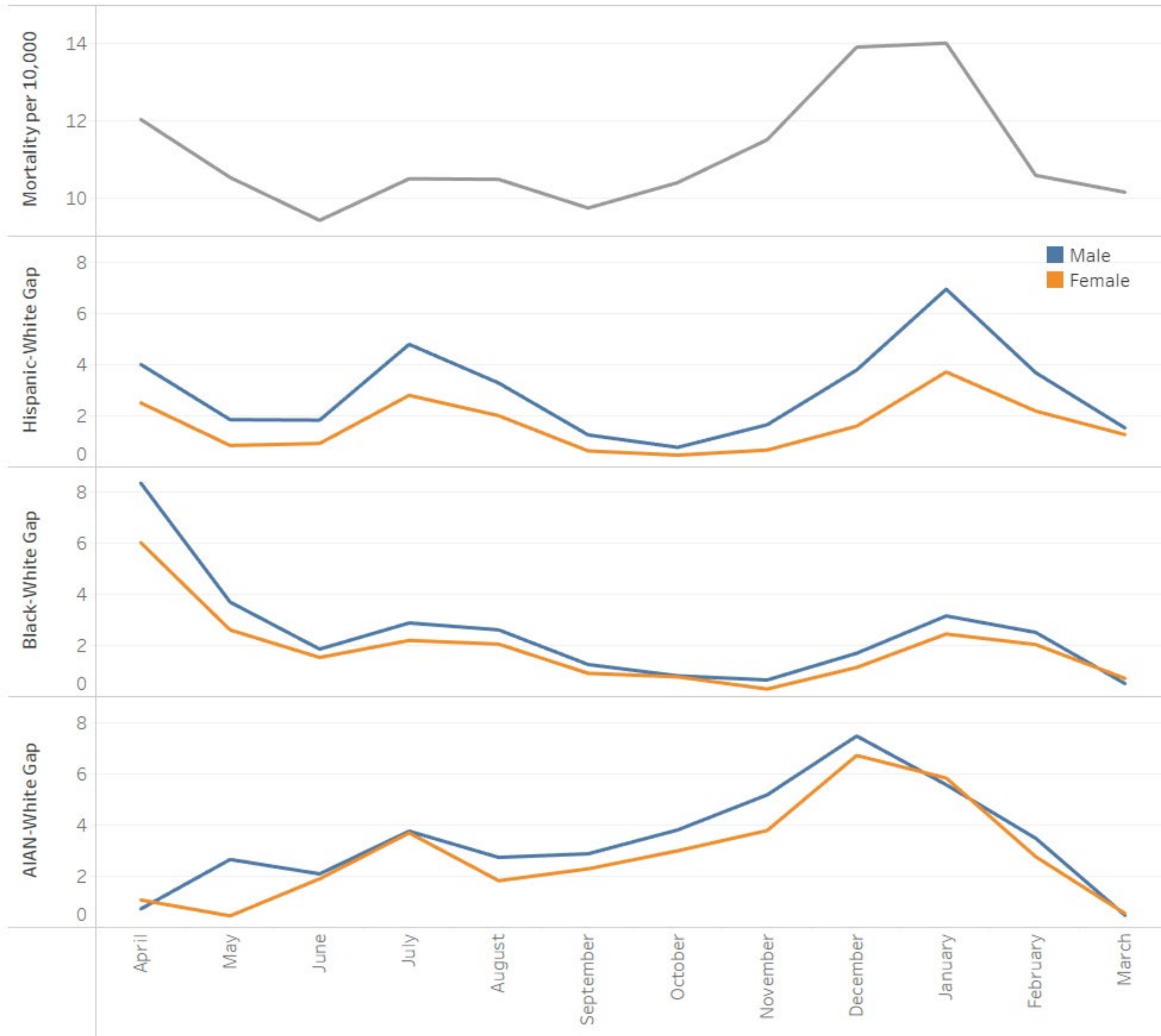
Figure 6: Age- and Sex-Adjusted Excess All-Cause Mortality by State and Pandemic Wave, April 2020 through March 2021



Note: Excess mortality is the difference between the observed population-standardized mortality rate and the expected population-standardized mortality rate. Expected mortality rates April 2020 to March 2021 are estimated using the prediction equation from a negative binomial regression predicting age- and sex-adjusted state- and wave-specific deaths for April 2010 to March 2020 as a function of a linear year term, categorical wave term, and a population exposure term. Note, also, that choropleth scales differ across panels.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); ACS (2001-2019); and various administrative and third-party location data (2010-2020). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response and a non-missing state location for any given year. DRB Approval Number: CBDRB-FY22-CES014-020.

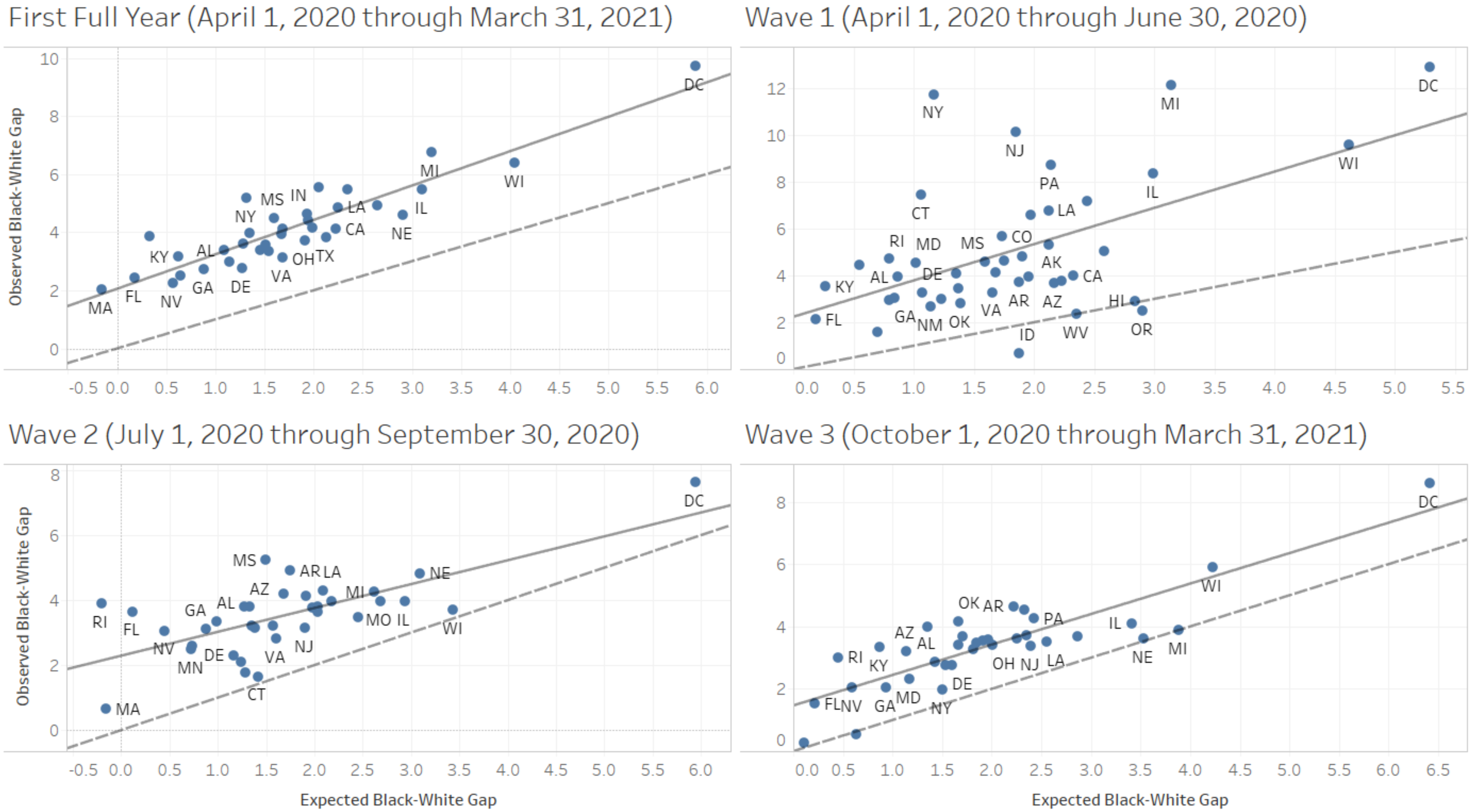
Figure 7: Age-Adjusted Racial/Ethnic Gaps in Excess All-Cause Mortality by Sex and Month, April 2020 through March 2021



Note: Excess mortality gaps are the raw differences between two racial/ethnic groups' excess mortality rates, where positive values indicate gaps in favor of NH Whites. Excess mortality is the difference between the observed population-standardized mortality rate and the expected population-standardized mortality rate. Expected mortality rates April 2020 to March 2021 estimated using the prediction equation from a negative binomial regression predicting age-adjusted sex- and race/ethnicity-specific deaths for April 2010 to March 2020 as a function of a linear year term, categorical month term, and a population exposure term.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

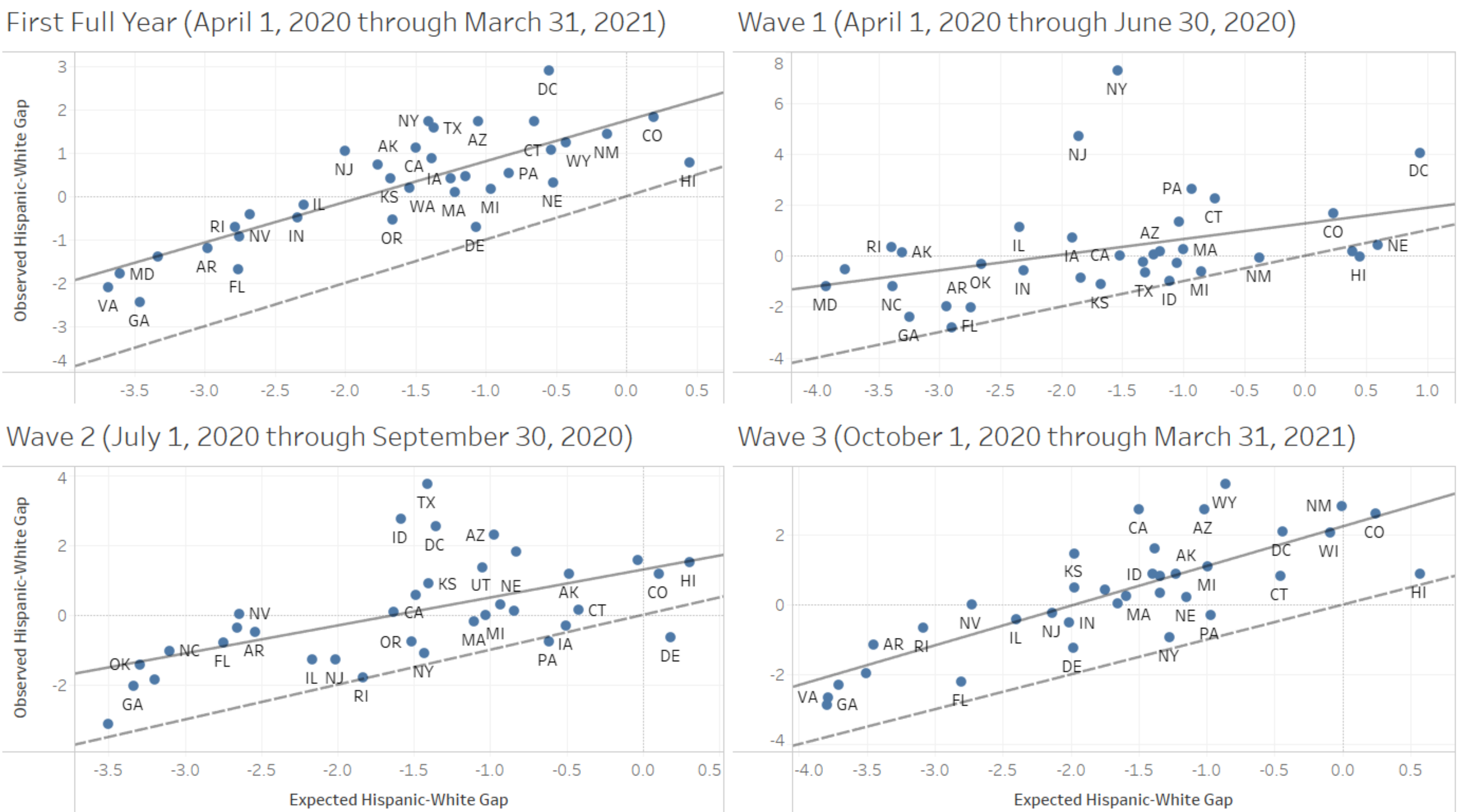
Figure 8: Age- and Sex-Adjusted Black-White Gaps in All-Cause Mortality by State and Wave, April 2020 through March 2021



Note: Dashed lines represent the 45-degree diagonal where y = x. Solid lines are the linear trends through plotted state points. Mortality gaps are the raw differences between mortality rates for NH Black alone and NH White alone individuals, where negative values indicate gaps in favor of NH Blacks. Expected mortality rates April 2020 to March 2021 estimated using the prediction equation from a negative binomial regression predicting age- and sex-adjusted race/ethnicity-specific deaths for April 2010 to March 2020 as a function of a linear year term, categorical wave term, and a population exposure term. Note, also, that axes differ across panels and states in which the NH Black Alone population share is less than 4 percent are omitted.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); ACS (2001-2019); and various administrative and third-party location data (2010-2020). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response and a non-missing state location for any given year. DRB Approval Number: CBDRB-FY22-CES014-020.

Figure 9: Age- and Sex-Adjusted Hispanic-White Gaps in All-Cause Mortality by State and Wave, April 2020 through March 2021



Note: Dashed lines represent the 45-degree diagonal where y = x. Solid lines are the linear trend through plotted state points. Mortality gaps are the raw differences between mortality rates for Hispanic and NH White alone individuals, where negative values indicate gaps in favor of Hispanics. Expected mortality rates April 2020 to March 2021 estimated using the prediction equation from a negative binomial regression predicting age- and sex-adjusted race/ethnicity-specific deaths for April 2010 to March 2020 as a function of a linear year term, categorical wave term, and a population exposure term. Note, also, that axes differ across panels and states in which the Hispanic population share is less than 4 percent are omitted.
Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); ACS (2001-2019); and various administrative and third-party location data (2010-2020). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response and a non-missing state location for any given year. DRB Approval Number: CBDRB-FY22-CES014-020.

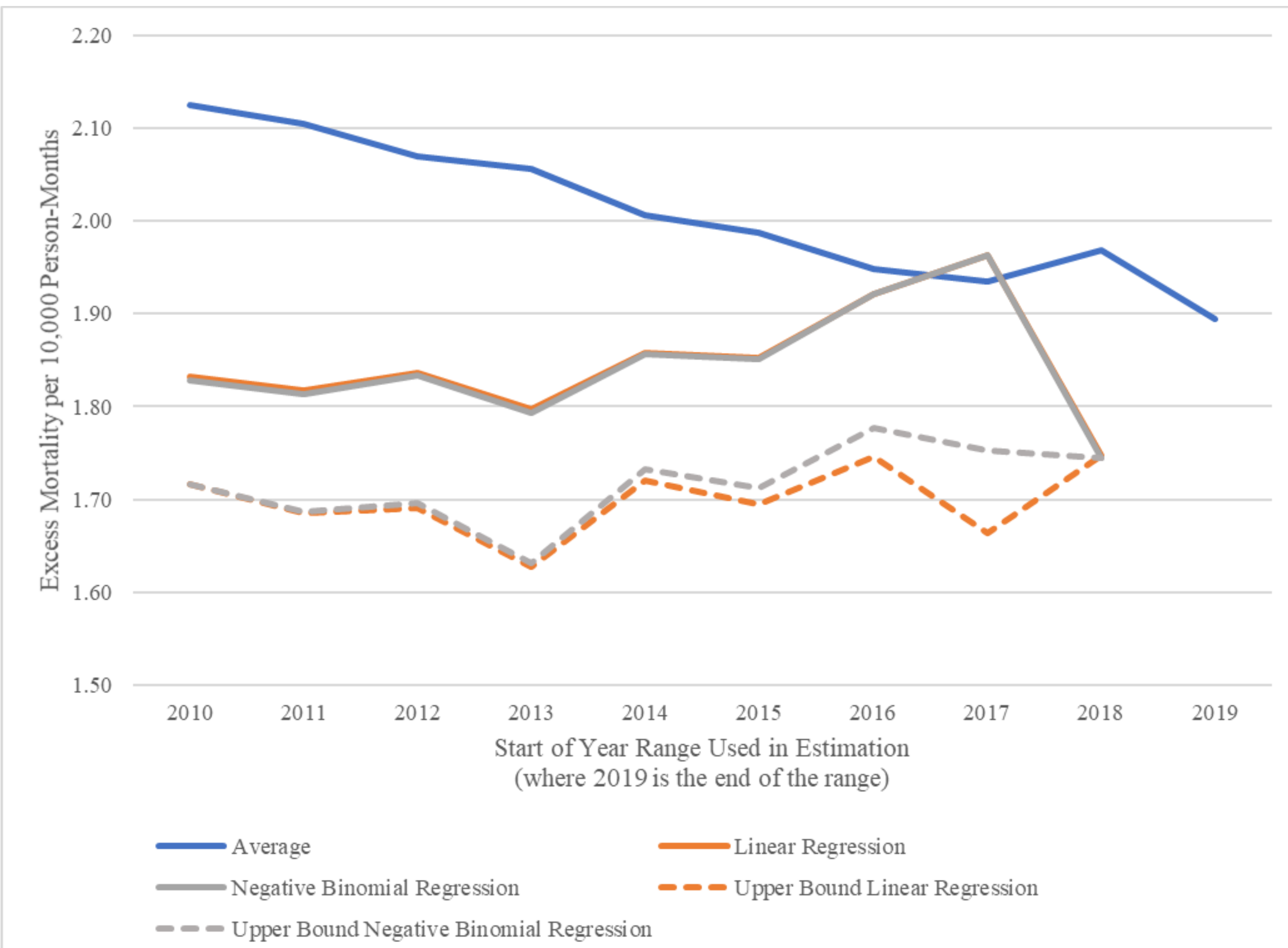
Appendix 1: Summary of the Restrictions Applied to Generate an Analytical Universe

	Count	Remaining in Universe
Individuals alive as of January 1, 2010	421,200,000	421,200,000
Missing DOB | Sex | Race/Ethnicity	126,300,000	294,900,000
Missing DOB	1,687,000	-
Missing Sex	6,069,000	-
Missing Race/Ethnicity	126,300,000	-
Born prior to 2010	82,520,000	-
Born 2010 or later	43,780,000	-
Born 2010 or Later	3,000,000	291,900,000
Under 15 or Over 99 Years of Age (average over all months, April 2010 to March 2021)	32,600,000	259,300,000

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-029.

Appendix 2: The impact of model and reference period selection on estimates of excess all-cause mortality

Estimating excess all-cause mortality during the first year of the pandemic requires the generation of an expected mortality rate that is likely to have prevailed in the hypothetical absence of COVID-19. We tested three methods for generating an expected mortality rate for the April 1, 2020 to March 31, 2021 period: (1) averaging mortality rates for the pre-pandemic period; (2) modeling the linear trend in mortality rates for the pre-pandemic period using linear regression; and (3) modeling death counts as a function of the population at risk using negative binomial regression.[13] For each of these methods, we also varied the length of the pre-pandemic reference period used to generate expected values. The figure below presents the excess mortality estimates resulting from each of these methods and pre-pandemic reference period ranges, where excess mortality is the difference between the observed and expected mortality rates (or, for dashed lines, the difference between the observed mortality rate and the upper bound of the 95% confidence interval around the expected mortality rate).



Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

[13] Overdispersion parameters are consistently statistically significant and, therefore, we reject the Poisson count model in favor of the more general negative binomial.

Because mortality rates have steadily increased over the last decade (see Figure 2), averaging mortality rates for the pre-pandemic period yields the least conservative estimates of excess mortality during the pandemic (solid blue line). Generally speaking, the longer the range of pre-pandemic data used when averaging, the lower the expected mortality rate and the higher the estimate of excess mortality during the pandemic. Not surprisingly, then, the most conservative estimates of excess mortality from this averaging method result from using only the 2019 mortality rate to generate an expected mortality rate for 2020. While this averaging method is simple and produces a reasonable estimate of expected mortality for the pandemic period, we do not adopt this method for our presentation of results because it fails to properly account for the steady rise in mortality in the pre-pandemic period.

Linear regression estimates of excess mortality improve upon averaging methods by taking the rise in mortality prior to the pandemic into account, generating an estimate of expected pandemic-era mortality in line with the prior trend (solid orange line, partially visible behind the solid gray line). Generally speaking, the longer the range of pre-pandemic data used in the linear regression, the higher the expected mortality rate and the lower the estimate of excess mortality during the pandemic; this pattern breaks down, however, when the reference period becomes too small – for example, when only one or two years of pre-pandemic era data are modeled.

Negative binomial regression estimates of excess mortality (solid gray line) are practically indistinguishable from linear regression estimates, but they reflect a fundamentally distinct modeling technique. Linear regression models predict the mortality rate given past trends but make no restrictions in the upper or lower bounds of the predicted rate. For example, given the positive slope in mortality trends since 2010, there is a point in the past at which the model underlying the solid orange line above would predict a *negative* mortality rate, as well as a point in the distant future at which it would predict a mortality rate *higher than 100 percent*. In contrast, the negative binomial regression model predicts the expected count of deaths (which cannot be negative and, therefore, sets a lower-bound on expected counts), taking the underlying population at risk into account (setting an upper-bound on expected counts, which cannot exceed the population at risk).

The subtle differences between the linear and negative binomial regression estimates are seen when we consider the uncertainty around expected values. This uncertainty can be seen in the figure above in the estimates of excess mortality using upper bound 95 percent confidence interval estimates from the linear and negative binomial models (the dashed orange and gray lines, respectively). Generally speaking, negative binomial models produce estimates with less uncertainty than linear models (particularly as we shrink the length of the reference period used in estimation) due, in large part, to the restrictions inherently placed on estimates. As a result, estimates of excess mortality based on upper bounds are more conservative for the linear than for the negative binomial results.

We present estimates in the main text of this paper derived exclusively from negative binomial regressions of mortality data for the period from April 1, 2010 to March 31, 2019. The negative binomial regression method provides conservative excess mortality estimates virtually indistinguishable from linear regression methods, but with less uncertainty and greater respect for the fundamental count- and population-based nature of the underlying Numident death data.

Appendix 3: Age-, Sex-, and Race/Ethnicity-Specific (Proportional) Excess All-Cause Mortality, April 2020 through March 2021

	Hispanic					NH White Alone				
Males	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected
15-24	0.70	0.03	0.89	0.19	26.95	0.76	0.05	0.82	0.06	7.99
25-34	1.31	0.05	1.71	0.40	30.74	1.61	0.11	1.73	0.13	7.77
35-44	1.75	0.06	2.54	0.79	45.25	2.12	0.05	2.49	0.37	17.47
45-54	2.92	0.04	4.73	1.82	62.29	3.77	0.04	4.42	0.65	17.26
55-64	6.63	0.05	10.92	4.29	64.73	8.60	0.10	9.79	1.19	13.87
65-74	14.90	0.14	25.50	10.60	71.14	17.41	0.23	20.61	3.20	18.38
75-84	36.93	0.80	59.38	22.45	60.79	43.89	0.64	52.76	8.87	20.21
85+	109.10	2.85	142.10	33.00	30.25	152.20	6.33	164.90	12.70	8.34
Females										
15-24	0.28	0.02	0.36	0.08	29.36	0.34	0.02	0.35	0.01	2.69
25-34	0.55	0.02	0.73	0.19	34.27	0.77	0.05	0.82	0.05	6.03
35-44	0.94	0.04	1.25	0.31	33.56	1.25	0.04	1.42	0.18	14.29
45-54	1.73	0.03	2.50	0.77	44.40	2.49	0.06	2.81	0.31	12.61
55-64	4.02	0.06	6.01	1.99	49.51	5.51	0.08	6.09	0.58	10.47
65-74	9.44	0.11	14.65	5.22	55.27	11.76	0.09	13.57	1.81	15.39
75-84	25.58	0.44	37.80	12.22	47.77	32.74	0.24	38.34	5.60	17.10
85+	88.85	2.47	113.60	24.75	27.86	128.10	4.24	140.20	12.10	9.45

	NH Black Alone					NH American Indian/Alaskan Native Alone				
Males	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected
15-24	1.39	0.06	1.91	0.52	37.62	1.58	0.13	1.78	0.20	12.67
25-34	2.21	0.08	3.00	0.79	35.56	3.57	0.18	4.64	1.06	29.74
35-44	2.96	0.09	3.98	1.02	34.29	4.77	0.24	7.04	2.27	47.48
45-54	5.09	0.19	7.06	1.97	38.76	7.82	0.22	11.55	3.73	47.74
55-64	11.82	0.20	15.72	3.90	32.99	14.35	0.60	20.88	6.53	45.51
65-74	25.22	0.33	34.08	8.86	35.13	27.04	0.54	37.06	10.02	37.06
75-84	54.79	0.75	73.34	18.55	33.86	58.82	1.13	79.08	20.26	34.44
85+	138.40	3.73	170.50	32.10	23.19	143.90	5.70	176.20	32.30	22.45
Females										
15-24	0.45	0.02	0.62	0.17	38.28	0.84	0.07	1.06	0.23	27.18
25-34	0.94	0.04	1.26	0.32	34.54	2.12	0.10	2.97	0.85	39.99
35-44	1.74	0.06	2.35	0.61	34.86	3.30	0.15	4.52	1.22	37.02
45-54	3.49	0.09	4.55	1.06	30.46	5.29	0.29	8.10	2.82	53.24
55-64	8.08	0.17	10.16	2.09	25.82	9.79	0.23	13.78	3.99	40.71
65-74	16.17	0.21	21.83	5.66	35.00	19.33	0.25	27.20	7.87	40.71
75-84	38.61	0.74	51.14	12.53	32.45	45.27	2.31	60.53	15.26	33.71
85+	112.40	3.04	139.80	27.40	24.38	129.40	4.99	151.90	22.50	17.39

Continued on the next page.

Note: The excess mortality and proportional excess mortality estimates reported here are also shown in Figures 4 and 5 of the main text.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

Appendix 3 (continued): Age-, Sex-, and Race/Ethnicity-Specific (Proportional) Excess All-Cause Mortality, April 2020 through March 2021

	NH Asian Alone					NH Native Hawaiian/Pacific Islander Alone				
Males	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected
15-24	0.41	0.04	0.40	-0.02	-4.33	0.92	0.31	0.77	-0.16	-16.99
25-34	0.66	0.02	0.73	0.07	11.02	1.57	0.48	1.84	0.27	17.43
35-44	0.80	0.04	1.04	0.24	30.32	2.73	0.42	3.21	0.48	17.51
45-54	1.52	0.05	1.97	0.45	29.57	5.14	0.48	7.89	2.75	53.38
55-64	3.94	0.04	5.32	1.38	35.04	10.63	0.39	14.23	3.60	33.87
65-74	9.73	0.15	13.60	3.87	39.82	21.86	0.96	28.51	6.65	30.42
75-84	26.67	0.54	36.40	9.73	36.48	48.81	2.39	58.00	9.19	18.83
85+	83.18	1.84	102.60	19.42	23.35	126.30	9.10	142.60	16.30	12.91
Females										
15-24	0.23	0.03	0.20	-0.02	-9.67	0.44	0.13	0.49	0.05	11.12
25-34	0.35	0.03	0.40	0.05	13.26	0.88	1.73	0.92	0.04	4.64
35-44	0.46	0.02	0.53	0.07	15.59	1.56	1.24	2.17	0.62	39.61
45-54	0.94	0.03	1.18	0.24	25.20	3.72	0.68	4.68	0.96	25.81
55-64	2.38	0.03	2.85	0.48	19.97	8.07	0.34	8.56	0.50	6.15
65-74	5.99	0.13	7.65	1.66	27.78	18.11	0.75	20.92	2.81	15.52
75-84	18.53	0.15	23.65	5.12	27.63	39.04	2.25	44.75	5.71	14.63
85+	71.02	1.66	86.17	15.15	21.33	110.20	13.17	124.30	14.10	12.79

	NH Some Other Race Alone					NH Multiple Race				
Males	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected	Expected	95% Confidence Interval	Observed	Excess	Excess as Proportion of Expected
15-24	0.69	0.14	0.87	0.18	26.70	0.80	0.05	0.97	0.16	20.49
25-34	1.42	0.23	1.73	0.31	21.89	1.52	0.07	1.75	0.23	15.20
35-44	1.47	0.35	1.54	0.07	4.90	2.03	0.08	2.51	0.48	23.72
45-54	2.79	0.87	3.91	1.12	40.05	3.68	0.11	4.71	1.03	27.92
55-64	6.35	0.51	8.04	1.69	26.62	9.35	0.28	10.80	1.45	15.50
65-74	13.07	0.70	20.21	7.14	54.63	20.75	0.55	23.97	3.22	15.52
75-84	35.73	3.61	47.25	11.52	32.24	46.97	1.10	57.19	10.22	21.76
85+	107.70	7.91	137.90	30.20	28.04	129.00	6.12	145.50	16.50	12.79
Females										
15-24	0.33	0.10	0.35	0.02	4.76	0.45	0.04	0.49	0.04	9.25
25-34	0.71	0.25	1.08	0.37	51.21	0.90	0.04	1.01	0.11	11.88
35-44	0.89	1.79	1.25	0.35	39.58	1.46	0.05	1.66	0.20	13.55
45-54	2.00	0.52	2.27	0.27	13.39	2.82	0.11	3.42	0.60	21.30
55-64	4.44	0.64	5.93	1.50	33.75	7.05	0.13	8.06	1.01	14.33
65-74	9.00	1.46	12.25	3.25	36.17	15.44	0.26	17.70	2.26	14.64
75-84	24.35	2.07	35.50	11.15	45.79	37.27	0.90	44.90	7.63	20.47
85+	86.18	8.74	108.80	22.62	26.25	115.40	6.37	131.90	16.50	14.30

Note: The excess mortality and proportional excess mortality estimates reported here are also shown in Figures 4 and 5 of the main text.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); and ACS (2001-2019). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity response. DRB Approval Number: CBDRB-FY22-CES014-020.

Appendix 4: Age- and Sex-Adjusted Excess All-Cause Mortality by State and Pandemic Wave, April 2020 through March 2021

	First Full Year (April 1, 2020 through March 31, 2021)				Wave 1 (April 1, 2020 through June 30, 2020)				Wave 2 (July 1, 2020 through September 30, 2020)				Wave 3 (October 1, 2020 through March 31, 2021)			
State	Expected	95% Confidence Interval	Observed	Excess	Expected	95% Confidence Interval	Observed	Excess	Expected	95% Confidence Interval	Observed	Excess	Expected	95% Confidence Interval	Observed	Excess
Missing	--	--	5.62	--	--	--	6.01	--	--	--	5.27	--	--	--	5.57	--
AL	11.56	0.17	14.08	2.52	11.39	0.17	12.60	1.22	11.29	0.20	14.24	2.96	12.03	0.40	15.39	2.96
AK	9.20	0.15	10.08	0.88	9.28	0.41	9.25	-0.03	8.73	0.56	10.03	1.30	9.62	0.36	10.97	1.30
AZ	9.01	0.19	11.26	2.25	9.01	0.19	10.33	1.32	8.71	0.12	11.35	2.64	9.34	0.34	12.11	2.64
AR	11.39	0.25	13.19	1.80	11.11	0.28	11.61	0.50	11.14	0.24	13.24	2.10	11.94	0.36	14.73	2.10
CA	7.71	0.12	9.38	1.67	7.63	0.12	8.41	0.78	7.35	0.11	8.98	1.63	8.17	0.23	10.77	1.63
CO	8.42	0.10	9.66	1.24	8.32	0.14	9.73	1.41	8.04	0.13	8.89	0.85	8.91	0.30	10.35	0.85
CT	8.22	0.05	10.04	1.81	8.19	0.10	11.98	3.79	7.85	0.11	8.17	0.32	8.65	0.15	9.95	0.32
DE	9.49	0.10	11.16	1.67	9.23	0.44	11.61	2.38	9.36	0.21	10.13	0.77	9.90	0.42	11.74	0.77
DC	9.15	0.22	11.96	2.81	8.93	0.62	14.37	5.44	9.07	0.25	9.96	0.88	9.48	0.45	11.57	0.88
FL	8.80	0.19	10.37	1.57	8.83	0.25	9.57	0.74	8.73	0.28	11.01	2.28	8.86	0.56	10.53	2.28
GA	10.16	0.10	12.49	2.33	10.01	0.06	11.51	1.50	9.89	0.11	12.70	2.81	10.60	0.27	13.26	2.81
HI	7.51	0.08	7.64	0.13	7.44	0.19	7.22	-0.22	7.42	0.19	7.85	0.43	7.68	0.16	7.84	0.43
ID	8.98	0.13	9.74	0.76	9.25	0.27	8.59	-0.66	8.58	0.36	10.05	1.47	9.16	0.25	10.58	1.47
IL	9.02	0.06	10.84	1.82	8.83	0.14	11.25	2.41	8.70	0.10	9.66	0.96	9.56	0.23	11.61	0.96
IN	10.56	0.12	12.19	1.63	10.37	0.21	11.98	1.61	10.14	0.16	11.21	1.07	11.18	0.33	13.36	1.07
IA	9.06	0.10	10.43	1.37	8.87	0.17	9.54	0.67	8.65	0.21	10.11	1.46	9.67	0.29	11.63	1.46
KS	9.60	0.08	10.88	1.28	9.43	0.17	9.64	0.21	9.34	0.15	10.37	1.03	10.05	0.29	12.62	1.03
KY	11.85	0.22	13.24	1.39	11.59	0.28	12.08	0.49	11.53	0.21	12.75	1.21	12.46	0.34	14.89	1.21
LA	10.99	0.17	13.87	2.88	10.81	0.20	13.82	3.01	10.73	0.17	13.92	3.19	11.44	0.42	13.87	3.19
ME	9.51	0.16	9.65	0.15	9.45	0.37	9.37	-0.09	9.11	0.20	9.46	0.35	9.98	0.21	10.13	0.35
MD	9.06	0.11	10.77	1.71	8.90	0.11	11.49	2.60	8.75	0.20	9.76	1.01	9.56	0.20	11.07	1.01
MA	8.23	0.10	9.68	1.45	8.18	0.21	11.92	3.74	7.82	0.11	7.77	-0.05	8.73	0.16	9.35	-0.05
MI	9.81	0.10	11.43	1.62	9.70	0.14	12.08	2.38	9.38	0.16	10.25	0.87	10.38	0.27	11.97	0.87
MN	8.13	0.08	9.13	1.00	7.89	0.15	9.03	1.15	7.97	0.12	8.44	0.48	8.55	0.12	9.91	0.48
MS	11.96	0.21	14.97	3.01	11.71	0.26	13.87	2.15	11.67	0.27	15.41	3.74	12.52	0.39	15.65	3.74

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Note: The excess mortality estimates reported here are also shown in Figure 6 of the main text.

Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); ACS (2001-2019); and various administrative and third-party location data (2010-2020). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity. DRB Approval Number: CBDRB-FY22-CES014-020.

Appendix 4 (continued): Age- and Sex-Adjusted Excess All-Cause Mortality by State and Pandemic Wave, April 2020 through March 2021

	First Full Year (April 1, 2020 through March 31, 2021)				Wave 1 (April 1, 2020 through June 30, 2020)				Wave 2 (July 1, 2020 through September 30, 2020)				Wave 3 (October 1, 2020 through March 31, 2021)			
State	Expected	95% Confidence Interval	Observed	Excess	Expected	95% Confidence Interval	Observed	Excess	Expected	95% Confidence Interval	Observed	Excess	Expected	95% Confidence Interval	Observed	Excess
MO	10.29	0.11	11.93	1.64	10.03	0.12	10.85	0.81	10.00	0.04	11.53	1.54	10.86	0.33	13.42	1.54
MT	9.14	0.14	10.09	0.95	8.88	0.22	8.99	0.11	9.01	0.21	9.68	0.67	9.54	0.26	11.60	0.67
NE	8.87	0.07	10.10	1.23	8.69	0.15	9.28	0.59	8.62	0.12	9.77	1.15	9.31	0.26	11.26	1.15
NV	9.46	0.16	11.20	1.74	9.45	0.27	10.16	0.71	9.20	0.16	11.36	2.16	9.75	0.34	12.09	2.16
NH	8.98	0.28	9.48	0.49	8.73	0.35	9.70	0.98	8.69	0.37	8.97	0.28	9.56	0.30	9.76	0.28
NJ	8.24	0.08	10.76	2.53	8.07	0.17	14.04	5.98	7.92	0.12	8.15	0.23	8.76	0.22	10.10	0.23
NM	9.53	0.10	11.62	2.10	9.45	0.28	10.96	1.52	9.22	0.30	10.74	1.52	9.93	0.15	13.17	1.52
NY	8.02	0.09	10.66	2.64	7.86	0.14	13.99	6.13	7.65	0.10	7.98	0.33	8.59	0.23	10.02	0.33
NC	10.17	0.10	11.68	1.51	10.03	0.17	10.80	0.76	9.75	0.13	11.47	1.72	10.76	0.26	12.78	1.72
ND	8.48	0.27	10.00	1.52	8.50	0.33	9.25	0.75	7.93	0.30	9.09	1.16	9.05	0.33	11.67	1.16
OH	10.33	0.11	11.91	1.58	10.12	0.14	11.08	0.96	10.00	0.08	11.19	1.19	10.89	0.23	13.46	1.19
OK	11.06	0.13	13.03	1.96	10.83	0.20	11.11	0.28	10.61	0.18	12.50	1.89	11.79	0.29	15.47	1.89
OR	8.72	0.14	9.29	0.57	8.64	0.18	8.75	0.11	8.43	0.19	9.17	0.74	9.11	0.22	9.94	0.74
PA	9.43	0.12	11.01	1.58	9.28	0.16	11.17	1.89	9.06	0.12	9.76	0.70	9.98	0.21	12.12	0.70
RI	8.85	0.13	10.38	1.53	8.71	0.28	11.40	2.69	8.55	0.32	8.83	0.28	9.30	0.24	10.91	0.28
SC	10.62	0.21	12.71	2.09	10.38	0.25	11.18	0.81	10.36	0.29	13.37	3.01	11.15	0.26	13.58	3.01
SD	8.83	0.27	10.38	1.55	8.59	0.37	8.95	0.36	8.63	0.36	9.69	1.06	9.29	0.33	12.51	1.06
TN	11.53	0.17	13.33	1.79	11.35	0.24	11.84	0.49	11.19	0.19	13.10	1.91	12.09	0.25	15.04	1.91
TX	9.33	0.14	11.77	2.45	9.16	0.19	9.95	0.80	9.01	0.10	12.48	3.47	9.83	0.29	12.89	3.47
UT	8.63	0.15	9.53	0.90	8.69	0.28	8.75	0.06	8.23	0.16	9.53	1.30	9.00	0.23	10.30	1.30
VT	8.50	0.15	8.92	0.42	8.38	0.31	8.88	0.50	7.97	0.20	8.35	0.37	9.18	0.28	9.55	0.37
VA	9.06	0.10	10.39	1.33	8.94	0.27	9.98	1.04	8.73	0.16	9.91	1.18	9.52	0.19	11.28	1.18
WA	8.32	0.09	8.89	0.56	8.20	0.19	8.54	0.34	7.99	0.13	8.78	0.79	8.79	0.26	9.33	0.79
WV	11.95	0.11	13.26	1.31	11.72	0.26	11.91	0.19	11.51	0.25	12.71	1.21	12.66	0.35	15.15	1.21
WI	8.78	0.11	9.88	1.11	8.52	0.16	9.19	0.67	8.51	0.19	9.35	0.84	9.31	0.13	11.11	0.84
WY	9.15	0.45	10.76	1.61	9.08	0.54	9.56	0.47	8.65	0.47	10.56	1.91	9.72	0.78	12.16	1.91

Note: The excess mortality estimates reported here are also shown in Figure 6 of the main text.
Sources: Census Numident (Q3, 2021); Decennial Census (2000, 2010); ACS (2001-2019); and various administrative and third-party location data (2010-2020). Restricted to individuals ages 15 to 99 at the start of any given month with a non-missing self-reported or household proxy race/ethnicity. DRB Approval Number: CBDRB-FY22-CES014-020.